# CALIFORNIA FISH AND GAME

"CONSERVATION OF WILDLIFE THROUGH EDUCATION"

VOLUME 72 JANUARY 1986 NUMBER 1

*California Fish and Game* is a journal devoted to the conservation and understanding of wildlife. If its contents are reproduced elsewhere, the authors and the California Department of Fish and Game would appreciate being acknowledged.

Subscriptions may be obtained at the rate of $10 per year by placing an order with the California Department of Fish and Game, 1416 Ninth Street, Sacramento, CA 95814. Money orders and checks should be made out to California Department of Fish and Game. Inquiries regarding paid subscriptions should be directed to the Editor.

Complimentary subscriptions are granted on an exchange basis.

Please direct correspondence to:

Perry L. Herrgesell, Ph.D., Editor
California Fish and Game
1416 Ninth Street
Sacramento, CA 95814

# CALIFORNIA FISH AND GAME

VOLUME 72 JANUARY 1986 NUMBER 1

*Published Quarterly by*

STATE OF CALIFORNIA

THE RESOURCES AGENCY

DEPARTMENT OF FISH AND GAME

*—LDA—*

# CONTENTS

*Calif. Fish and Game* 72(1): 4–16 1986

# POPULATION CHARACTERISTICS OF PACIFIC HERRING, *CLUPEA HARENGUS PALLASI,* IN HUMBOLDT BAY, CALIFORNIA [1]

DOUGLAS J. RABIN [2] AND ROGER A. BARNHART
California Cooperative Fishery Research Unit
Humboldt State University
Arcata, California 95521

**Population characteristics of Pacific herring, *Clupea harengus pallasi,* were determined for spawning stocks in Humboldt Bay. Fecundity was estimated to be 220 ± 35 eggs per gram. Biomass of hearring was estimated to be 372 tons (237mt) in 1974–75 and 232 tons (210mt) in 1975–76. Spawning occurred from early December to early March both years, primarily in north Humboldt Bay. Two- and three-year-old herring accounted for about 46% and 57% by number respectively for the 1974–75 and 75–76 spawning stocks.**

## INTRODUCTION

In 1972, Japan removed its import quota on herring roe which stimulated the market for herring and encouraged development of herring fisheries from California to Alaska. The present study was designed to obtain information needed for management of the Humboldt Bay herring fishery.

The biology of Pacific herring, *Clupea harengus pallasi,* has been extensively studied for more than half a century (Rounsefell 1930, Taylor 1964, Blankenbeckler 1978, Spratt 1981). Pacific herring spawning grounds extend from southern California along the North Pacific rim to Japan. Spawning occurs in inshore waters, bays, and estuaries, beginning in the late fall in California and lasting up to four months.

When herring schools move into shallow inshore waters, they become highly vulnerable to commercial fisheries. Fishery managers must know when spawning occurs and where spawning schools are located to regulate the fishery. The objectives of the present study were (i) record the time and distribution of herring spawning in Humboldt Bay for two seasons, (ii) estimate biomass of the spawning population and of the spawning substrate, and (iii) determine age structure, maturity, and sex ratio of adult herring in Humboldt Bay. A concurrent study determined the fecundity of Humboldt Bay herring (Rabin and Barnhart 1977).

## DESCRIPTION OF STUDY AREA

The 22.4 km-long Humboldt Bay is about 144 km south of the California-Oregon border (Figure 1). It is a marine embayment having small localizaed habitats with true estuarine characteristics (U.S. Army Corps of Engineers 1976). Skeesick (1963) presented an extensive description of the physical and chemical characteristics of Humboldt Bay.

---

[1] Part of a thesis submitted by the senior author to Humboldt State University in partial fulfillment of a Master of Science degree.

[2] Mr. Rabin's present address is: P.O. Box 342, Kirkland, Washington 98033. Accepted for publication March 1985.

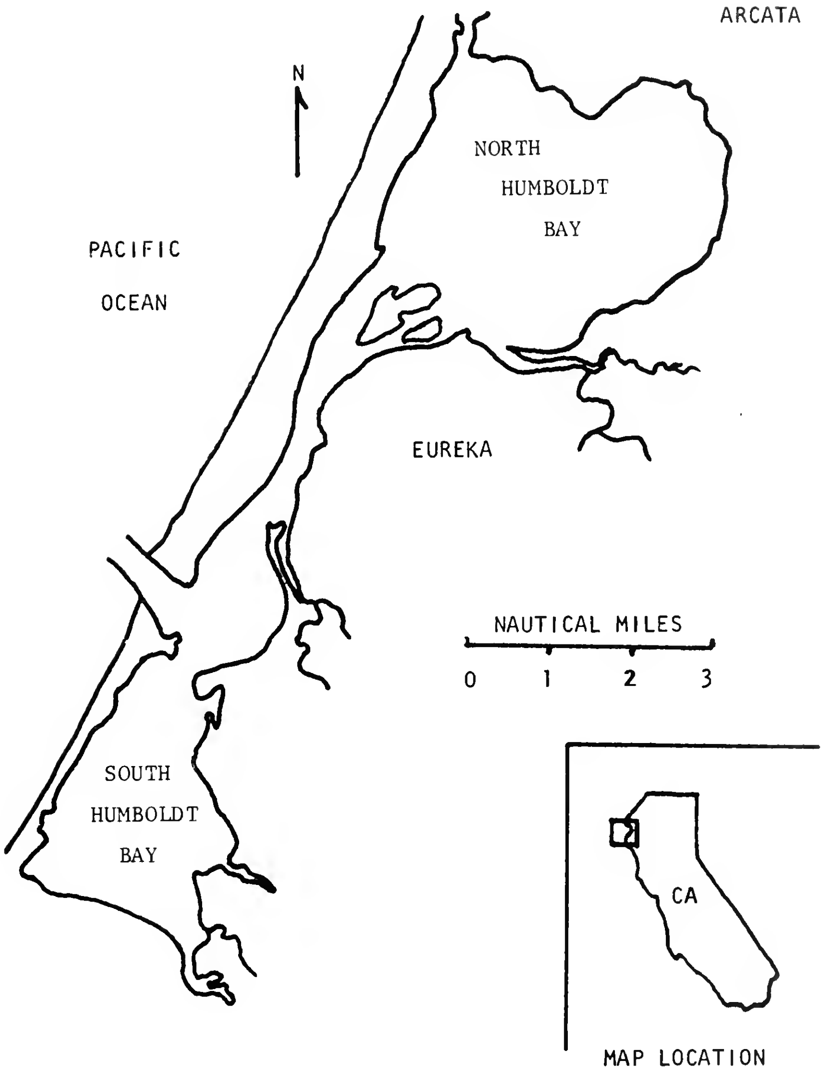


FIGURE 1. Map of Humboldt Bay, California

Large beds of eelgrass, *Zostera marina,* grow from mud flats that characterize north and south Humboldt Bay (Figures 2 and 3). Harding, Butler, and Heft (1975) estimated that the north and south bays had 4.35 X $10^6$ $m^2$ and 8.86 X $10^6$ $m^2$ of eegrass, respectively. Mud flats and eelgrass beds are exposed at most minus tides and are divided by a network of narrow channels. Distribution of eelgrass is limited primarily to shallow mud flat areas due to high water turbidity and tidal scouring along channel edges. Eelgrass is the primary herring spawning substrate in Humboldt Bay.

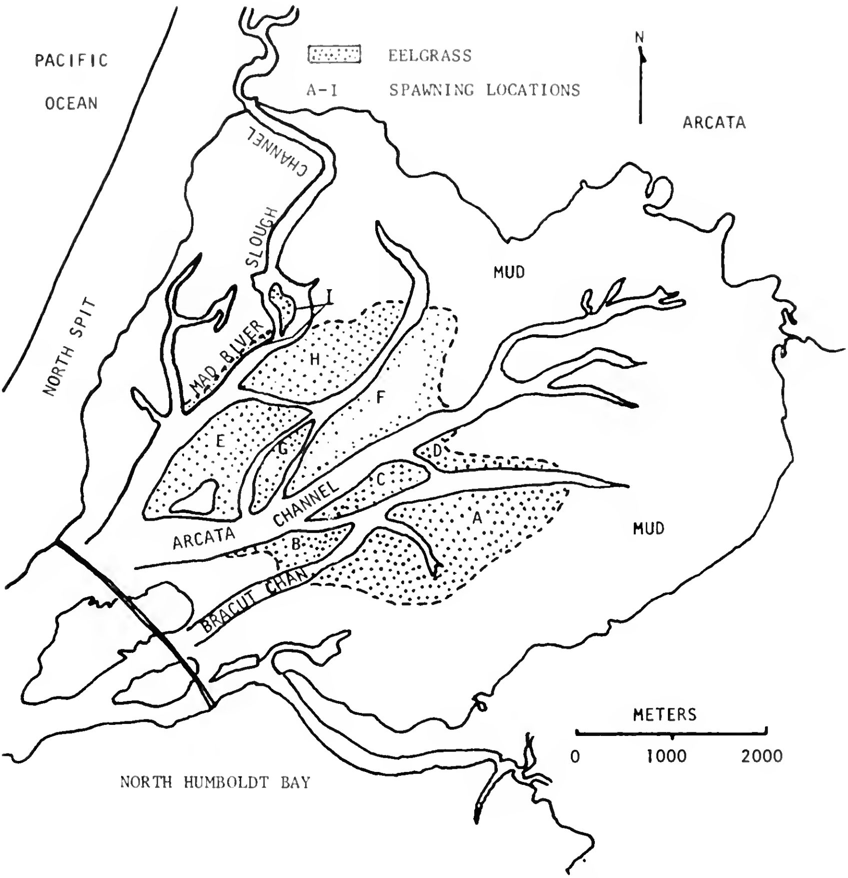


FIGURE 2. Map of north Humboldt Bay at 0-tide. Stippled areas indicate eelgrass distribution for winters 1974–75 and 1975–76.

## HISTORY OF FISHERY

The Bay has supported a relatively small bait and commercial herring fishery for over 50 years. A total of about 630 t of herring were harvested from 1926–76; the largest annual catch, 63 t was taken in 1943. There were no commercial landings of herring in 1965–72. In 1975 and 1976, 1 and 11 t respectively, were caught under temporary state legislation allowing a winter harvest of 20 t. The state increased the harvest quota to 50 t in 1977 and the quota was approached each year from 1979 through 1981 and exceeded in 1982 (Table 1). The quota was increased to 60 t in 1983.

## METHODS AND MATERIALS

### Fish Sampling

Herring were caught in 1974–75 with a variable mesh sinking nylon gill net, 38.1 by 1.8 m with equal lengths of 1.3, 1.9, 2.5, 3.2 and 3.8 cm bar mesh. The net was allowed to soak no more than 10 min per set in areas where birds and seals were actively feeding. During 1975–76 a 60.9 by 6.1 m beach seine was used for sampling and a recording fathometer used to locate the fish.

The following data were recorded for each fish sampled; standard length in mm, weight to the nearest 0.1 g, sex, and maturity. Scales were removed for age determination. Fish caught in the 1974–75 season were categorized as being either immature, having undeveloped gonads, or mature, with gonads filling the body cavity (Bagenal and Braum 1971). In the 1975–76 season mature fish were further categorized as having opaque (ripening) or translucent (ripe) eggs.

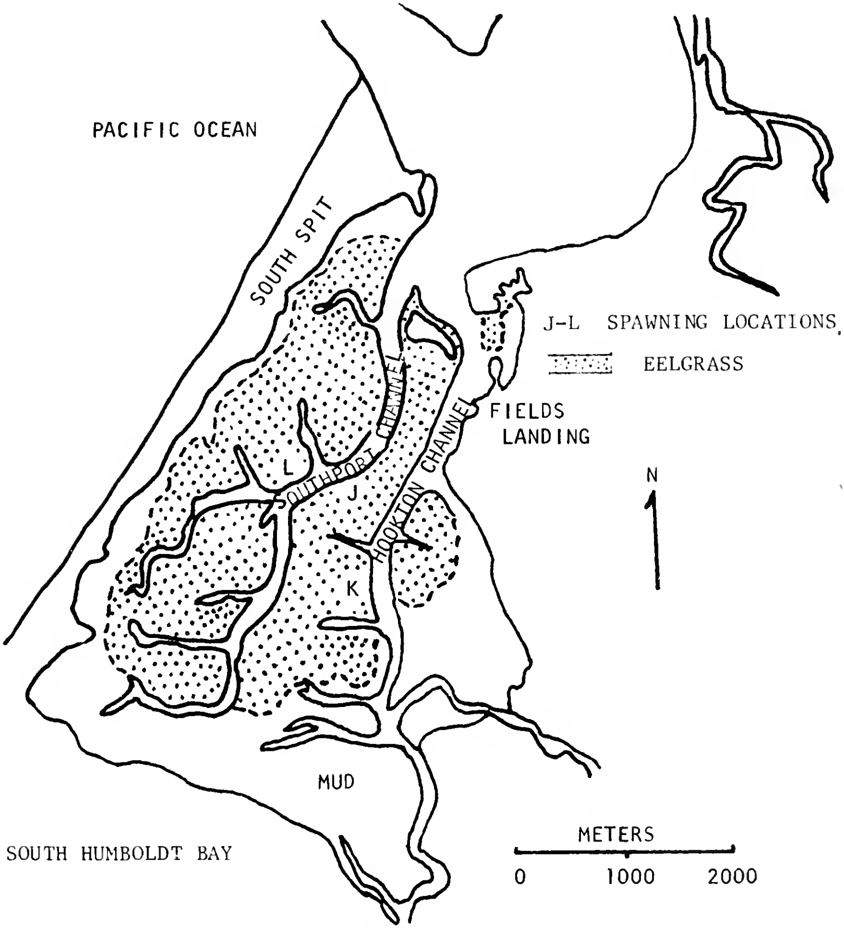


FIGURE 3. Map of south Humboldt Bay at 0-tide. Stippled areas indicate eelgrass distribution for winters 1974–75 and 1975–76.

Scales used for age determination were taken from the area below and anterior to the dorsal fin, then mounted between two glass plates and aged without reference to fish length. An annulus at the outer edge of the scale was assumed on scales of herring caught during the spawning season. For example, a herring hatched in January 1974 and caught in January 1976 was considered a 2-year-old, although showing only one annulus inside the scale margin.

**TABLE 1. Pacific Herring Landings, Humboldt Bay, California. 1974–1983.**

| Year | * Landings Tons | Pounds | Quota (tons) |
|---|---|---|---|
| 1974 | 0.2 | 500 | 20 |
| 1975 | 1.0 | 2,000 | 20 |
| 1976 | 11.6 | 23,134 | 20 |
| 1977 | 21.5 | 42,949 | 50 |
| 1978 | 11.7 | 23,417 | 50 |
| 1979 | 49.4 | 98,831 | 50 |
| 1980 | 49.5 | 98,981 | 50 |
| 1981 | 43.0 | 85,920 | 50 |
| 1982 | 51.6 | 103,280 | 50 |
| 1983 | 9.5 | 18,980 | 60 |

* Ron Warner, California Department of Fish and Game Eureka, Ca. (pers. comm.).

## Spawn Surveying

Time, distribution, and density of spawns were determined for the winters of 1974–75 and 1975–76. From late November to late March, daily surveys of eelgrass beds were conducted, alternating days between north and south Humboldt Bay. Surveying was done from a 5 m flat bottom boat. Two garden rakes, wired back to back and attached to the boat with a 10 m rope, were used to uproot eelgrass and examine it for attached eggs. The rake was used to outline spawning areas with the aid of buoys, duck blinds, and other landmarks as reference points. We installed 5 m wood poles as additional channel markers to facilitate surveying at higher tides.

The modified rake was randomly cast from a boat in a spwaning area to obtain 3–16 samples of 100–400 g of eelgrass on which eggs had been deposited in order to calculate mean number of eggs per kg of eelgrass. The size of the spawning area and density of egg deposition determined the number of samples collected. After roots were removed, each sample was placed in a plastic bag, brought to the laboratory, rinsed clean of sediment, and allowed to drain. Leaves were weighed to the nearest 0.1 g and preserved in 10% formalin. Eggs in each sample were hand counted and mean number of eggs per kg of eelgrass was estimated for each spawning area.

Fish sometimes spawned two or more times in areas that already contained unhatched eggs. Even though the first spawn had already been measured and sampled it was difficult to determine the extent of overlap and relative density of the more recent egg deposition. In such instances water temperature and egg development were monitored and hatching time for the first spawn was predicted according to Alderdice and Velson (1971) and Taylor (1971). After the first eggs hatched, the more recently deposited eggs were measured and sampled as a single unit. The estimates were calculated and reported as separate spawns.

Mean weight/$m^2$ of eelgrass was obtained by sampling eelgrass during daytime minus tides in February and March. A 0.15 $m^2$ hoop was cast randomly in areas where spawning occurred. Eelgrass rooted within the hoop was cut to exclude the roots and bagged. Samples were brought to the laboratory, rinsed clean of sediment, drained, and weighed to the nearest 0.1 g. Mean weight/$m^2$ values were derived each winter for areas having light and medium eelgrass growth, as classified by Harding (1973).

Number of kilograms of eelgrass on which eggs were laid was determined by multiplying the spawning area in $m^2$ by mean weight of eelgrass per $m^2$ within the same area. We used a polar planimeter and Coast and Geodetic Survey chart of Humboldt Bay to measure the previously outlined spawning area.

### Fecundity

The mean number of eggs per gram of fish was derived from a concurrent fecundity study of Humboldt Bay herring (Rabin and Barnhart 1977). We determined the mean number of eggs per gram of female herring to be 220 ± 35 (95% CI) for ages 2–9.

### Biomass Estimation

Biomass of herring in each spawning school was determined by the following equation:

$$A = \frac{B\ C}{D} \text{ where:}$$

A = grams of fish spawning
B = kilograms eelgrass on which eggs were deposited
C = mean number of eggs per kilogram of eelgrass
D = mean number of eggs per gram of spawning adults (sexes combined)

Confidence limits of final biomass estimates were calculated from the combined variance for eggs/kg eelgrass of all samples taken for the respective season.

The sex ratio of adult herring in both years did not differ significantly from 1:1, therefore, the value (D) used for fish biomass computations was 220/2 or 110 eggs per gram of herring for both sexes.

## RESULTS

### Age and Growth Relationships

During January and early February 1975, herring were caputured near spawning areas using a variable-mesh gill net. In 1976 a beach seine was used to capture herring. Adult herring, 2 to 11 years old, were found in the spawning populations in both years. For 1974–75 and 1975–76, respective mean lengths ranged from 157 to 230 mm and 166 to 223 mm, and mean weights from 63 to 195 g and 79 to 178 g (Table 2). Two-years-olds from the 1975–76 catch were markedly longer and heavier than 2-year-olds from the 1974–75 catch. Length overlapped considerably among all adjacent age groups (Figure 4). Two- and three-year-old herring far outnumbered all other age groups (Figure 5) but were not distinguishable by length alone (Figure 6).

Ages 2 and 3, combined, accounted for 57.1% by number and 43.8% by weight of fish spawning in 1975–76 (Table 2). No young of the year or yearlings were taken in either season.

### Maturity

Of 408 adult herring examined in 1974–75, 96% were mature. All herring caught in 1975–76 were mature; most (99%) were in ripe or running ripe condition.

**TABLE 2. Year Class Statistics for Humboldt Bay, Pacific Herring Caught During Winters 1974–75 and 1975-76.**

| *Season and age group* | *Year class* | *Number* | *Percent number* | *Percent weight* | *Mean standard length (mm)* | *Mean weight (g)* |
|---|---|---|---|---|---|---|
| 1974–75 | | | | | | |
| 2 | 1973 | 75 | 29.6 [1] | 15.3 | 157 | 63 |
| 3 | 1972 | 42 | 16.6 | 14.0 | 179 | 103 |
| 4 | 1971 | 41 | 16.2 | 16.2 | 190 | 122 |
| 5 | 1970 | 19 | 7.5 | 9.4 | 205 | 153 |
| 6 | 1969 | 11 | 4.3 | 6.5 | 212 | 181 |
| 7 | 1968 | 19 | 7.5 | 10.7 | 212 | 173 |
| 8 | 1967 | 30 | 11.9 | 18.0 | 218 | 185 |
| 9 | 1966 | 11 | 4.4 | 7.0 | 224 | 195 |
| 10 | 1965 | 3 | 1.2 | 1.7 | 217 | 173 |
| 11 | 1964 | 2 | 0.8 | 1.2 | 230 | 191 |
| 1975–76 | | | | | | |
| 2 | 1974 | 97 | 33.6 [2] | 22.9 | 166 | 79 |
| 3 | 1973 | 68 | 23.5 | 20.9 | 183 | 102 |
| 4 | 1972 | 33 | 11.4 | 12.3 | 197 | 123 |
| 5 | 1971 | 28 | 9.7 | 12.1 | 204 | 142 |
| 6 | 1970 | 14 | 4.8 | 6.8 | 212 | 159 |
| 7 | 1969 | 10 | 3.5 | 5.1 | 217 | 168 |
| 8 | 1968 | 25 | 8.7 | 13.0 | 219 | 170 |
| 9 | 1967 | 10 | 3.5 | 4.9 | 218 | 160 |
| 10 | 1966 | 3 | 1.0 | 1.6 | 221 | 178 |
| 11 | 1965 | 1 | 0.3 | 0.4 | 223 | 153 |

[1] From gill net catches.
[2] From seine catches.

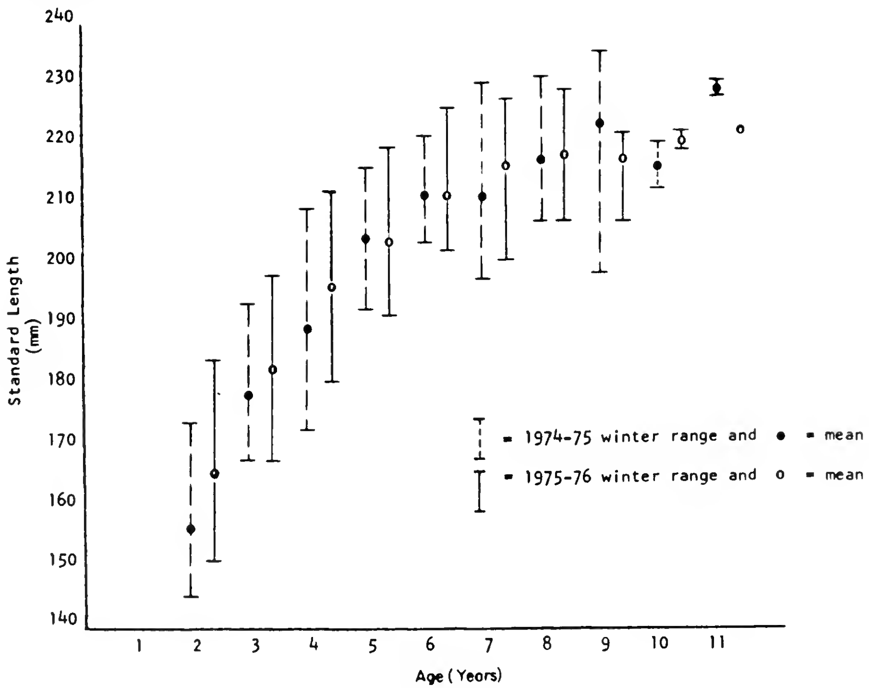


FIGURE 4. Age and length relationships for Humboldt Bay herring caught during winters 1974–75 and 1975–76.

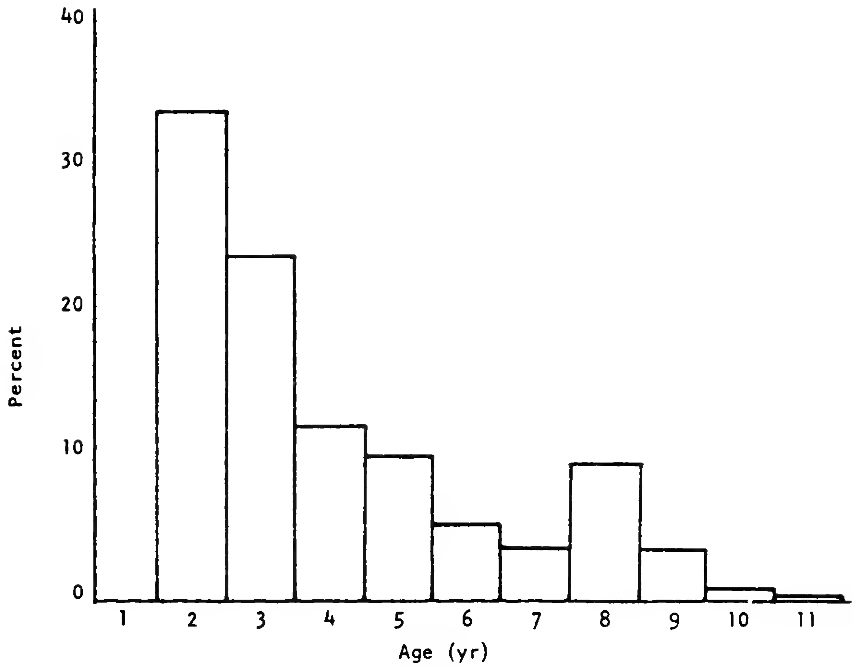


FIGURE 5. Age composition of 289 Humboldt Bay herring, January 1976.

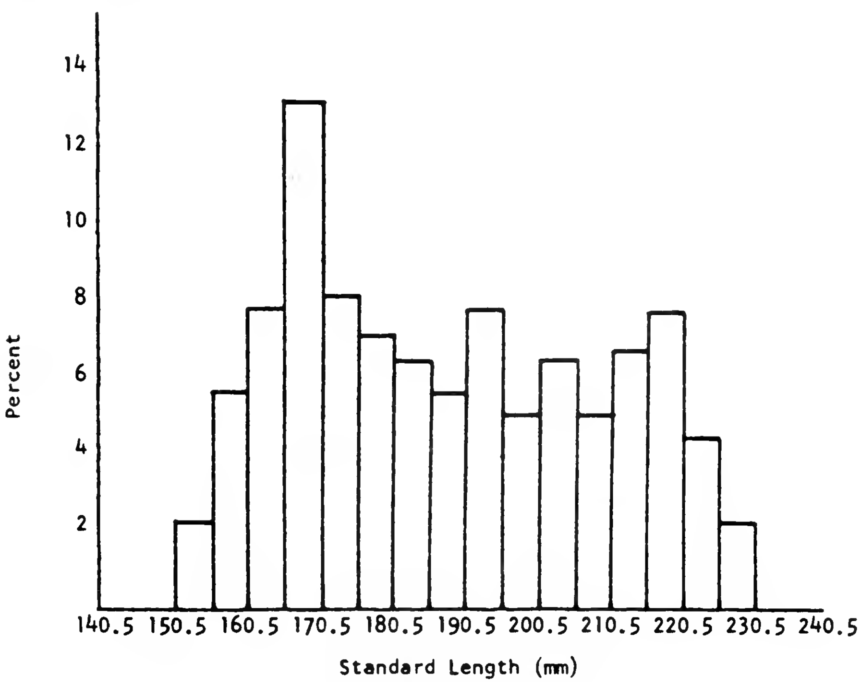


FIGURE 6. Length groups for 289 Humboldt Bay herring, January 1976.

### Eelgrass Biomass Estimates

Eelgrass biomass estimates for areas where spawning occurred were derived from 50 samples taken in 1974–75 and 71 samples in 1975–76 (Tables 3, 4).

Eelgrass density was variable from year to year. In 1975–76 eelgrass biomass in north Humboldt Bay was 25% less than in 1974–75. However, areas classified by Harding (1973) as having light eelgrass growth (Figure 2, areas A–D) had more eelgrass biomass each year than did Harding's areas of medium growth (Figure 2, areas E–I).

Eelgrass biomass per unit of area is typically higher in south Humboldt Bay than in north Humboldt Bay (Harding 1973). Spawning biomass estimates for south Humboldt Bay are conservative because due to time constraints we used north bay eelgrass density values in our calculations.

### Herring Biomass Estimation

Random samples of eggs on eelgrass were collected nine times in 1974-75 and eight times in 1975–76. The number of spawns each winter was greater than the number of sampling dates, judging by the occurrence of intermittent overlapping spawning. These intermittent spawnings were observed in January and February of both seasons.

Spawning began in mid-December and ended in early March; about 99% occurred between December 14 and February 14. More than 99% of the total egg deposition was in north Humboldt Bay—80% in the eelgrass beds southeast of Bracut channel (Figure 2, Area A).

Estimated Humboldt Bay Pacific herring spawning biomass was 372 ± 8 t in 1974–75 and 232 ± 6 t (95% CI) in 1975–76. In addition 1 t (0.9mt) of adult herring was taken commercially in 1974–75 and 11 t (10mt) were caught in 1975–76 in Humboldt Bay (Tables 3, 4).

## DISCUSSION

Most herring spawning took place in Humboldt Bay during December through March, the same months in which spawning occurred in San Francisco and Tomales Bays, California (Spratt 1976, 1981). Eighty percent of all spawning in Humboldt Bay occurred in the North Bay eelgrass beds nearest the creeks flowing into the bay. South Humboldt Bay receives comparatively little fresh water and was practically unused by herring—even though South Bay has more than twice the eelgrass biomass of North Bay. Outram (1951) found that low salinity water stimulated herring to spawn while in captivity. Taylor (1971) reported that hatching success decreases with increasing salinity. The location of fresh water inflow apparently influenced the location of herring spawning in Humboldt Bay.

Seasonal catches of Humboldt Bay herring did not exceed 12 t (10,980 kg) from 1959 through 1976. From 1979 through 1982 landings approximated 50 t annually. We believe that the population characteristics during our data collection period resemble those of an unexploited resource.

Our sampling data show full recruitment of herring into the spawning stock at age 2. Spratt (1981), from his work on San Francisco and Tomales Bay herring populations, states that California herring enter the spawning population at 2 years of age and by age 3 all herring are mature. Recruitment of British Columbia

**TABLE 3. Herring Spawning Data for 1974–75 Season, Humboldt Bay, CA.**

| Sampling date | Location[1] | Eggs on eelgrass (mean no./kg) | Eelgrass ($kg/m^2$) | Eggs ($no./m^2$) | Area ($m^2$) | Number of eggs spawned ($X 10^6$) | Fish spawning[2] kg | Fish spawning[2] Tons |
|---|---|---|---|---|---|---|---|---|
| 10 Dec 74 | A | 12,055 | 0.53 | 6,389 | 33,613 | 214.8 | 1,952 | 2.2 |
| 20 Dec 74 | A | 7,560 | 0.53 | 4,007 | 1,838,825 | 7,368.2 | 66,983 | 73.8 |
| 20 Dec 74 | C | 2,124 | 0.53 | 1,126 | 16,199 | 18.2 | 166 | 0.2 |
| 22 Dec 74 | E | 3,190 | 0.44 | 1,404 | 258,081 | 362.1 | 3,292 | 3.6 |
| 04 Jan 75 | A | 11,998 | 0.53 | 6,359 | 1,838,825 | 11,693.1 | 106,301 | 117.2 |
| 04 Jan 75 | C | 6,472 | 0.53 | 3,430 | 16,199 | 55.5 | 505 | 0.6 |
| 09 Jan 75 | B | 5,225 | 0.53 | 2,769 | 100,813 | 279.2 | 2,538 | 2.8 |
| 18 Jan 75 | A | 4,047 | 0.53 | 2,145 | 1,838,825 | 3,944.3 | 35,857 | 39.5 |
| 22 Jan 75 | E,G,H,I | 2,518 | 0.44 | 1,108 | 1,629,134 | 1,805.1 | 16,410 | 18.1 |
| 08 Feb 75 | A,B | 9,832 | 0.53 | 5,211 | 2,109,003 | 10,990.0 | 99,909 | 110.1 |
| 08 Feb 75 | C | 5,300 | 0.53 | 2,809 | 104,845 | 294.5 | 2,677 | 3.0 |
| 25 Feb 75 | K | 8,412 | 0.53 | 4,458 | 1,338 | 6.0 | 54 | 0.0 |
| 25 Feb 75 | L | 22,844 | 0.53 | 12,107 | 10,534 | 127.5 | 1,159 | 1.3 |
| Totals | | | | | 9,796,234 | 37,158.5 | 337,805 | 372.4 |
| Commercial catch | | | | | | | 909 | 1.0 |
| Total fish biomass | | | | | | | 338,714 | 373.4 |

[1] See Figure 2 or 3 for designated eelgrass beds. Areas J, M, and H were not sampled; the numbers of spawners were small and the numbers of eggs deposited too low to be significant.
[2] A sex ratio of 1:1 and a mean no. eggs/g female herring of 220 ± 35 was found: A value of 110 eggs/g of herring of both sexes used to calculate kg of spawning fish.

**TABLE 4. Herring Spawning Data for 1975–76 Season, Humboldt Bay, CA.**

| *Sampling date* | *Location*[1] | *Eggs on eelgrass (mean no./kg)* | *Eelgrass ($kg/m^2$)* | *Eggs ($no./m^2$)* | *Area ($m^2$)* | *Number of eggs spawned ($X 10^6$)* | *Fish spawning*[2] | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | *kg* | *Tons* |
| 20 Dec 75 | A | 6,516 | 0.43 | 2,802 | 1,838,825 | 5,152.4 | 46,839 | 51.6 |
| 26 Dec 75 | B | 5,017 | 0.43 | 2,157 | 98,780 | 213.1 | 1,937 | 2.1 |
| 05 Jan 76 | A | 2,152 | 0.43 | 925 | 1,838,825 | 1,700.9 | 15,463 | 17.0 |
| 09 Jan 76 | B | 5,878 | 0.43 | 2,528 | 104,845 | 265.0 | 2,410 | 2.7 |
| 11 Feb 76 | B | 11,041 | 0.43 | 4,748 | 270,178 | 1,282.8 | 11,662 | 12.9 |
| 11 Feb 76 | A | 9,585 | 0.43 | 4,122 | 1,838,825 | 7,579.6 | 68,906 | 76.0 |
| 11 Feb 76 | C | 5,972 | 0.43 | 2,568 | 310,503 | 797.4 | 7,249 | 8.0 |
| 14 Feb 76 | D,F,G,H,I | 13,796 | 0.23 | 3,173 | 1,814,630 | 5,757.8 | 52 345 | 57.7 |
| 10 Mar 76 | A | 5,173 | 0.43 | 2,224 | 177,430 | 394.6 | 3,587 | 4 0 |
| Totals | | | | | 8,692,841 | 23,143.6 | 210,398 | 231.9 |
| Commercial catch | | | | | | | 10,000 | 11.0 |
| Total fish biomass | | | | | | | 220,398 | 242.9 |

[1] See Figure 2 or 3 for designated eelgrass beds. Area D was not sampled; the numbers of spawners were small and the number of eggs desposited too low to be significant.
[2] A sex ratio of 1:1 and a mean no. eggs/g female herring of 220 ± 35 was found: A value of 110 eggs/g of herring of both sexes used to calculate kg of spawning fish.

herring occurs primarily at ages 3 and 4 (Outram and Hymphreys 1974). The infrequency of spawning checks or false annuli on the scales we examined indicated that the herring spawning season in Humboldt Bay does not overlap significantly with the resumption of growth in late winter and spring.

Since seasonal abundance of eelgrass in north Humboldt Bay can be substantially influenced by water quality (Harding 1973), bird feeding rates (Yocum and Keller 1961), and oyster culture (Waddell 1964), the annual change in eelgrass density we observed was not unusual. Our eelgrass biomass values represent only the wet weight of eelgrass leaves since the rhizome is an inaccessible substrate for herring eggs.

Field observations indicate that herring eggs do not adhere well to eelgrass coated with sediment or decaying epiphytes. Our herring biomass estimates are conservative due to the detachment of eggs between sampling periods, which Hart and Tester (1934) attribute to wave action.

Although bird predation of herring eggs can account for high removal rates of eggs before hatching (Cleaver and Frannett 1946, Outram 1958, Steinfeld 1972, Spratt 1981), we believe that predation was not a significant factor in the calculation of Humboldt Bay herring biomass estimates. Few to no bird aggregations were observed at Humboldt Bay spawning sites, regardless of tidal height. Spawning intensity was relatively light, which according to Spratt (1976) makes bird predation on eggs difficult.

Our 1974–75 and 1975–76 spawning biomass estimates of 372 t (337mt) and 232 t (210mt) should be useful for management purposes. Humboldt Bay can sustain a small commercial herring fishery from mid-December through March each year. North Bay eelgrass beds, the primary spawning locale of Humboldt Bay herring, should be given maximum protection to insure adequate herring reproduction in the bay.

## ACKNOWLEDGMENTS

This work was performed as part of NOAA Sea Grant Contract 04-5-158-28, "Studies on the biology of Northern Anchovy and Pacific Herring in Humboldt Bay" under the direction of the California Cooperative Fishery Research Unit, U.S. Fish and Wildlife Service. We appreciate the efforts of K. Bates, D. Chessmore, M. Dresner, S. Eisele, E. Spurling and associated personnel of the California Cooperative Fishery Research Unit. Our thanks to the California Department of Fish and Game which provided some matching funds for the project and especially biologist J. Spratt who provided considerable guidance in the early phases of our research.

## LITERATURE CITED

Alderdice, P.F. and F.P.J. Velson. 1971. Some effects of salinity and temperature on early development of Pacific herring, *Clupea pallasi.* Can. Fish. Res. Board, Jog., 28:1545–1562.

Bagenal, T.B., and E. Braum. 1971. Eggs and early life history. Pages 166–198 in W.E. Ricker, ed. Methods for assessment of fish production in fresh waters. 2nd ed. Blackwell Scientific Publications, Oxford.

Blankenbeckler, D. 1978. Age, growth, maturation and parasite occurrence of Pacific herring *Clupea pallasii* from southeastern Alaska, 1974 through 1976. Alaska Dept. Fish Game Tech. Data Rep. No. 39. 88 p.

Cleaver, F.C., and D.M. Franett. 1946. The predation by seabirds upon the eggs of Pacific herring, *Clupea pallasii,* at Holms Harbor during 1945. State of Washington, Dep. Fish., Div. Sci. Res., Biol. Rep. 46 B, 18 p.

Harding, L.W. Jr. 1973. Primary production in Humboldt Bay. Thesis, Humboldt State College, Arcata, Ca, 55 p.

Harding, L.W., Jr., J.H. Butler, and R.E. Heft. 1975. The standing stock and production of eelgrass, *Zostera marina* L. in Humboldt Bay, California. Lawrence Livermore Lab., Livermore, CA., No. UCRL-76987. 18 p.

Hart, J.L. and A.L. Tester. 1934. Quantitative studies on herring spawning. Trans. Am. Fish. Soc., 64:307–312.

Outram, D.N. 1951. Observations on the retention and spawning of the Pacific herring. Prog. Rep. Biol. Stn. Nanaimo and Prince Rupert 87:32–33.

———. 1958. The magnitude of herring spawn losses due to bird predation on the west coast of Vancouver Island. Fish. Res. Board Can. Pac. Prog. Rep., 111:9–13

Outram, D.N. and R.D. Humphreys. 1974. The Pacific herring in British Columbia waters. Fish. Mar. Serv., Pac. Biol. Stn. Circ., 100, 26 p.

Rabin, D.J. and R.A. Barnhart. 1977. Fecundity of Pacific herring, *Clupea harengus pallasi*, in Humboldt Bay. Calif. Fish. Game, 63(3):193–196.

Rounsefell, G.A. 1930. Contribution to the biology of the Pacific herring, *Clupea pallasii*, and the condition of the fishery in Alaska. Bull. U.S. Bur. Fish., 45:227–320.

Skeesick, D.G. 1963. A study of some physical-chemical characteristics of Humboldt Bay. Thesis, Humboldt State College, Arcata, CA, 148 p.

Spratt, J.D. 1976. The Pacific herring resource of Tomales Bay and San Francisco Bay, California: Its size and structure. Calif. Fish Game, Mar. Resources Tech. Rep. 33, 44 p.

———. 1981. Status of the Pacific herring, *Clupea harengus pallasii*, resource in California 1972 to 1980. Dept. of Fish Game, Fish Bull. (171), 107 p.

Steinfeld, J.D. 1972. Distribution of Pacific herring spawn in Yaquina Bay, Oregon, and observation on mortality through hatching. Thesis, Oregon State Univ., Corvallis, 75 p.

Taylor, F.H.C. 1964. Life history and present status of British Columbia herring stocks. Can. Fish. Res. Board, Bull., 143, 81 p.

———. 1971. Variation in hatching success in Pacific herring, *Clupea pallassii*, eggs with water depth, temperature, salinity and egg mass thickness. Rapp. P.-V. Reun. Cons. Int. Explor. Mer, 160:34–41.

U.S. Army Corps of Engineers. 1976. Navigation channel improvements authorized for Humboldt Harbor and Bay, Humboldt County, California. U.S. Army Corps of Engineers Draft Environmental Statement. San Francisco District, CA. 79 p.

Waddell, J.E. 1964. The effect of oyster culture on eelgrass, *Zostera marina*, L., Thesis, Humboldt State College, Arcata, CA, 48 p.

Yocum, C.F., and M. Keller. 1961. Correlation of food habits and abundance of waterfowl, Humboldt Bay, California. Calif. Fish Game, 47:41–53.

*Calif. Fish and Game* 72(1): 17–37 1986

# THE STRIPED BASS SPORT FISHERY IN THE SACRAMENTO-SAN JOAQUIN ESTUARY, 1969–1979 [1]

JAMES R. WHITE
California Department of Fish and Game
Bay-Delta Fishery Project
4001 N. Wilson Way
Stockton, California 95205

**The fishery for striped bass in the Sacramento-San Joaquin Estuary is described from tag returns and a bay-area creel census. Annual harvest averaged 18% and was higher for bass ≥age 5. Annual catch ranged from about 100,000 to 400,000 fish and declined after 1976. Angler effort and success (catch/ang h) also declined in the late 1970's. The catch varied both seasonally and geographically; 80% of the catch occurred from May through November, mostly in San Francisco Bay. Private boat anglers took 65% of the catch, shore/pier anglers took 21%, and charter boat anglers 14%. Fork length of bass in the catch averaged 65.1 cm, but exhibited a downward trend and varied among segments of the fishery. Age 3, 4, and 5 bass comprised two-thirds of the catch; age 4 typically was the most numerous group. Female bass were more numerous than males in the bay area catch in 10 of 11 years. Trends and anomalies in these data are discussed in relation to striped bass population characteristics, environmental factors and methodological bias.**

## INTRODUCTION

Striped bass, *Morone saxatilis,* are the object of an extensive sport fishery in the Sacramento-San Joaquin Estuary. During the period covered by this report (1969–1979), sportfishing regulations included a three-fish bag limit and a minimum total length (TL) of 40.6 cm. Angling occurs throughout the year, but activity varies seasonally in accordance with striped bass migrations. In summer and fall, anglers fish the ocean beaches with bait or by casting lures. Boat anglers fish San Francisco Bay and the Pacific Ocean (Figure 1) by drifting live anchovies or shiner perch or by trolling lures. In San Pablo Bay and Carquinez Strait there is a summer evening troll fishery and from San Pablo Bay upstream many anglers still-fish with bait such as staghorn sculpins ("bullheads"), *Leptocottus armatus*; yellowfin gobies ("mudsuckers"), *Acanthogobius flavimanus*; bay shrimp, *Crangon* sp.; northern anchovies, *Engraulis mordax*; sardines, *Sardinops* sp.; and threadfin shad, *Dorosoma petenense,* primarily in fall and winter. During spring, most fishing is in the Delta and upriver areas where anglers troll artificial lures or fish with bait.

My report describes this striped bass fishery from 1969 to 1979. Information is presented on harvest rate; the magnitude, distribution, and length, age and sex composition of the catch; fishing effort; and catch rates. Changes in these catch statistics reflect the condition of the fishery and assist in evaluating resource management decisions.

## METHODS

Harvest rates, annual catch, the seasonal and geographic distribution of the catch, and the contribution of charter boats, private boats and shore or pier were estimated from tag returns.

[1] Accepted for publication April 1985.

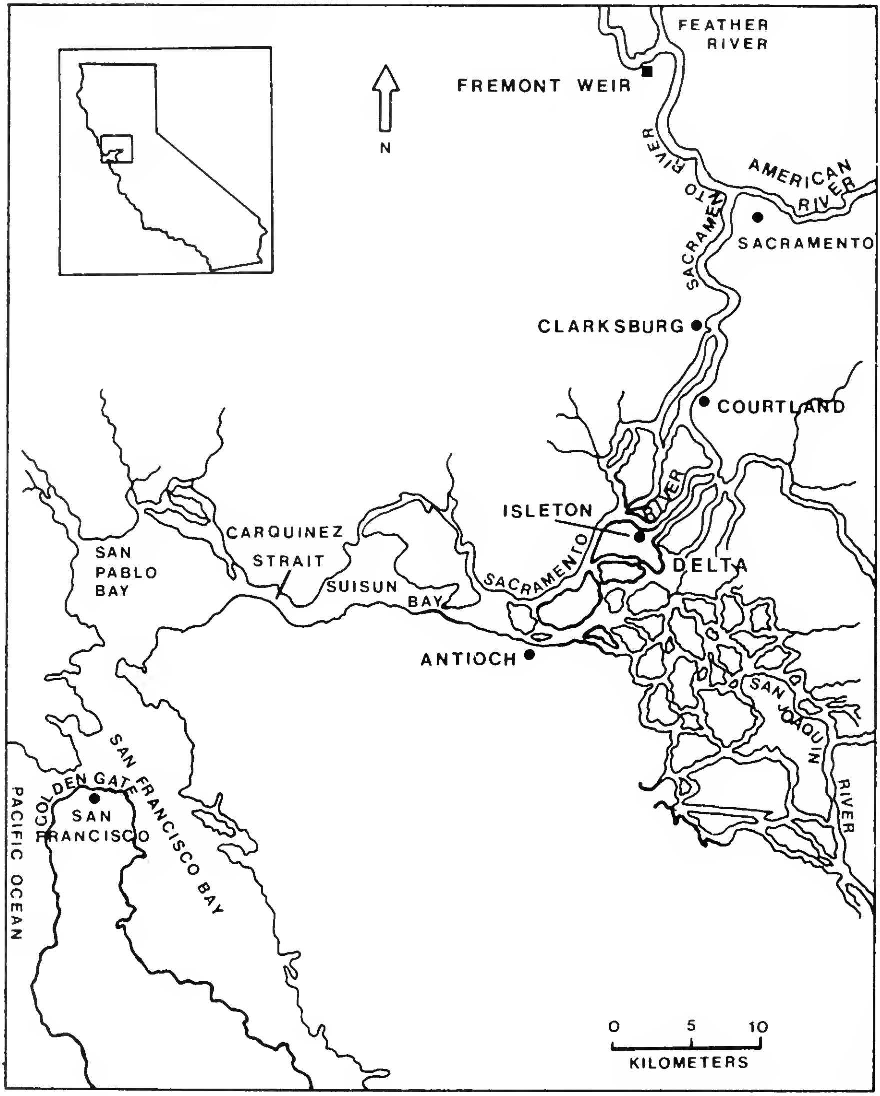


FIGURE 1. Sacramento-San Joaquin River System and Estuary.

Legal size striped bass ( ≥40.6 cm TL, about age 3 and older) were tagged during their spring spawning migration, on the San Joaquin River near Antioch and on the Sacramento River between Isleton and Fremont Weir, but primarily near Clarksburg (Figure 1). Approximately 4,000–18,000 bass were tagged annually, about 12% of these with $2, $5, $10, or $20 reward tags.

Tags recovered from 0 to 365 days after tagging were designated first year returns. Since tagging occurred for up to 3 months each spring, recovery years do not coincide with any specific calendar period, but generally run from spring to spring.

Tags were recovered mostly from anglers who voluntarily returned them in the mail, but also during an annual creel census in the San Francisco-San Pablo Bay area. Tags observed during the creel census were assumed to be completely reported; but uncensused anglers did not return all tags that they recovered. Hence, before calculating harvest rates, mail returns were adjusted for nonresponse based on ratios of return rates of tags of different reward denominations.

I estimated harvest rate using the equation:

$$\hat{u}_t = \frac{1}{M_t} \left(R_c + \frac{R_m}{r}\right)$$

where: $\hat{u}_t$ = harvest rate in year t

$M_t$ = number of nonreward tags applied at the beginning of year t

$R_c$ = number of nonreward tags applied at the beginning of year t and recovered during the creel census that year

$R_m$ = number of nonreward tags applied at the beginning of year t and returned in the mail during year t

r = estimated response rate during year t (ratio of nonreward:$20 tag return rate, Stevens, et al. 1985)

I estimated total annual catch of striped bass which were legal size in the spring using the equation:

$$\hat{C} = \hat{u}\hat{N}$$

where: $\hat{C}$ = estimated catch

$\hat{u}$ = estimated harvest rate

$\hat{N}$ = estimated abundance of adult bass.

The abundance of adult bass (Stevens 1977*a*, Stevens et al. 1985) was estimated using the modified Petersen method (Bailey 1951).

Angler success (bass/angler h) and the length, age, and sex composition of the summer and fall catch in the San Francisco-San Pablo Bay area were determined from the creel census. This census was conducted daily from Wednesday through Sunday at four to 12 ports. It sampled anglers fishing from lower Suisun Bay to the Pacific Ocean (Figure 1).

Census effort was about the same each year except 1977 and 1978 when private boats were not sampled and charter boat sampling was reduced by 75–80%.

Standard statistical tests (Sokal and Rohlf 1969) were used to evaluate significant trends and differences in the various catch statistics. Arcsin transformations were used before applying these tests to percentages.

## RESULTS

### Angler Response and Harvest Rate

Angler response, the estimated fraction of recovered nonreward tags that anglers actually return, decreased over the years of study. Response estimatation assumed all recovered $20 tags were returned. However, because $20 tags were not released every year, linear regressions were calculated to describe decreases in tag return rate ratios of nonreward:$5, $5:$10 and $10:$20 tags, and the three return rate ratios predicted annually from these regressions were multiplied to estimate response for each year (Stevens et al. 1985). Response ranged from 0.58 in 1969 to 0.36 in 1979 (Table 1).

**TABLE 1. Summary of Striped Bass Tagging Program in the Sacramento-San Joaquin Estuary.**

| *Year* | *Bass tagged* | *Total 1st year tag returns* [1] | *Response rate* | *Bass observed in creel census* |
|---|---|---|---|---|
| 1969 | 16,419 | 2,787 | 0.576 | 18,458 |
| 1970 | 14,380 | 1,625 | 0.551 | 21,043 |
| 1971 | 18,182 | 2,860 | 0.528 | 18,399 |
| 1972 | 18,368 | 2,690 | 0.504 | 32,381 |
| 1973 | 15,383 | 2,131 | 0.481 | 25,715 |
| 1974 | 13,785 | 2,616 | 0.460 | 38,703 |
| 1975 | 8,853 | 1,801 | 0.439 | 26,993 |
| 1976 | 10,510 | 1,854 | 0.419 | 21,481 |
| 1977 [2] | 4,955 | 860 | 0.398 | 4,073 |
| 1978 [2] | 4,255 | 416 | 0.379 | 1,461 |
| 1979 | 11,072 | 1,478 | 0.360 | 7,437 |

[1] Tags recovered within 365 days of tagging date; includes mail returns of nonreward tags corrected for nonresponse, mail returns of reward tags, and tags recovered during the creel census.

[2] Tagging effort reduced from two gill net boats and fyke traps to one gill net boat; private boats not sampled, charter boat census effort reduced by 75–80%.

From 1969 to 1979, an average of about 18% of the legal-size bass population was harvested annually (Table 2). Estimated harvest rate declined substantially from 20% in 1969 to about 13% in 1970 and then increased each year through 1974 when it reached 22%. It remained at that level from 1974 to 1976. The harvest rate declined in 1977 and again in 1978 to 11%, the lowest level for the 11-year period. It increased again to almost 18% in 1979, very close to the 11-year average.

**TABLE 2. Estimated Harvest Rate, Legal-Size Abundance and Annual Catch of Striped Bass in the Sacramento-San Joaquin Estuary, 1969–1979.**

| *Year* | *Estimated harvest rate* ($\hat{u}$) | *Estimated legal-size bass abundance* ($\hat{N}$) | *Estimated annual catch* ($\hat{C} = \hat{u}\hat{N}$) |
|---|---|---|---|
| 1969 | 0.201 | 1,646,000 | 330,800 |
| 1970 | 0.133 | 1,727,000 | 229,700 |
| 1971 | 0.158 | 1,600,000 | 252,800 |
| 1972 | 0.170 | 1,883,000 | 320,100 |
| 1973 | 0.174 | 1,637,000 | 284,800 |
| 1974 | 0.222 | 1,477,000 | 327,900 |
| 1975 | 0.218 | 1,850,000 | 403,300 |
| 1976 | 0.229 | 1,563,000 | 357,900 |
| 1977 | 0.183 | 885,000 | 162,000 |
| 1978 | 0.106 | 1,009,000 | 107,000 |
| 1979 | 0.178 | 1,125,000 | 200,300 |
| Mean | 0.179 | | 270,600 |
| Standard Deviation | 0.0379 | | 89,600 |

Harvest rate trends were about the same for both sexes. Sex stratified rates were calculated for ages 3 and 4 combined and ages $\geq 5$. Except for females in 1978, bass age 5 and above were harvested at consistently higher rates than 3 and 4-year-olds (Figure 2).

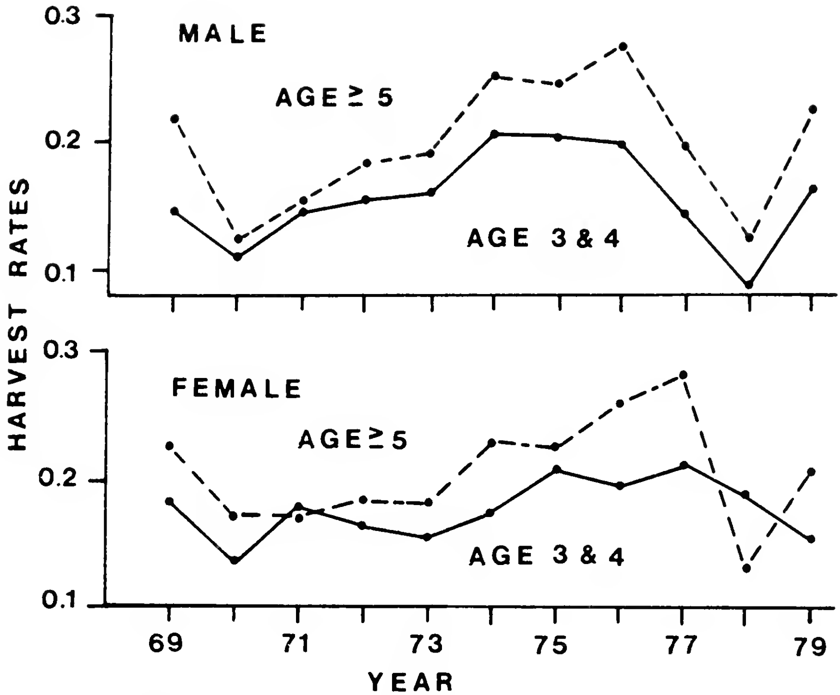


FIGURE 2. Harvest rate estimates stratified by age and sex for striped bass in the Sacramento-San Joaquin Estuary.

## Annual Catch

From 1969 to 1979, annual catch estimates ranged from about 107,000 to 403,000 striped bass (Table 2). Catch fluctuated with no significant trend ($t = 0.30$, $P > 0.90$) from 1969 to 1976; however, it declined substantially in 1977 and remained low through 1979. The 1977–1979 average of 156,400 bass was significantly less than the 1969–1976 mean catch of 313,400 ($t = 4.28$, $P < 0.005$).

## Seasonal and Geographic Distribution

The harvest of tagged bass was stratified according to recovery month and area to approximate the seasonal and geographic distribution of the catch. These distributions are approximations for several reasons: (i) immature female bass (ages 3 and 4) are underrepresented in the tagged group because many do not migrate to the spawning grounds where tagging occurs; (ii) recruitment of newly legal (40.6 cm) untagged fish occurs after tagging; and (iii) due to mortality, tagged fish become less available with time after tagging. The latter two factors cause tag returns to increasingly underrepresent the monthly catch as time passes which, in turn, affects the apparent geographic distribution of the catch because peak fishing periods differ among areas.

Monthly tag returns were low in winter, increased during spring, leveled off during summer, and reached a peak in the fall before declining to winter levels (Figure 3). More than 80% of the annual returns were from bass caught from May through November. Recoveries were highest in October and November.

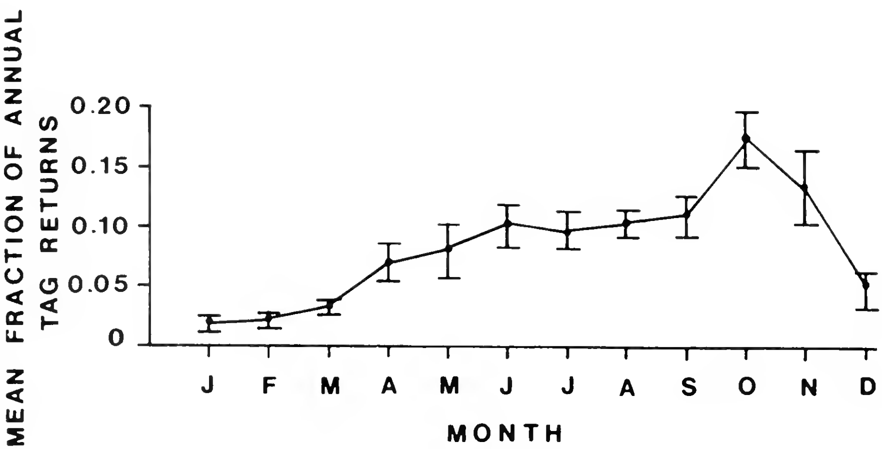


FIGURE 3. Monthly distribution of striped bass harvest in the Sacramento-San Joaquin Estuary based on mean first year returns of nonreward tags from 1969 to 1979. Mail returns were corrected for response rate. Vertical bars represent ±2 standard errors.

In general, San Francisco Bay provided more tag recoveries than other regions. From 1969 to 1979, these recoveries averaged 35% of the annual total, but the proportion was highly variable, ranging from about 20% in 1979 to 54% in 1974 (Table 3).

San Pablo Bay-Carquinez Strait returns averaged about 21% of the total.

Suisun Bay averaged 6.1% and the Delta averaged 19.8% of the total annual returns. The percentage of tag returns from the Delta exceeded the 11-year average each year from 1976 to 1979 resulting in a statistically significant ($t = 3.17$, $P < 0.01$) increasing trend. The percentage of returns from Suisun Bay also was relatively high during the last 4 years, particularly in 1978 and 1979, but the 11-year trend was not statistically significant because returns were lower from 1973–1975 than in earlier years.

About 15% of annual tag returns were from the Sacramento River upstream from the Delta. On the average, returns were equally divided between the section from Courtland to the Feather River (including the American River) and the section upstream from there including the Feather River and its tributaries.

The fewest tag recoveries came from the San Joaquin River and the Pacific Ocean. Only about 1% or less of annual returns were from the upper San Joaquin River. An average of 2.3% of annual returns were from the Pacific Ocean, although in 1977 an exceptional 8.4% came from the ocean. Although bass migrate to the ocean every year, they become available to anglers only when they congregate near shore, particularly off beaches south of the Golden Gate.

## Fishing Mode

Anglers returning tags were asked if they caught their fish on a charter boat, private boat, or from shore or pier. This allowed the annual catch to be apportioned accordingly using all returns, including tags applied in previous years.

**TABLE 3. Geographic Distribution of Annual Striped Bass Harvest in the Sacramento-San Joaquin Estuary Based on the Percent of 1st Year Returns of Nonreward Tags. Mail Returns Corrected for Nonresponse. Returns from Unknown Areas Not Included.**

| | FISHING AREA | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *Year* | *Pacific Ocean* | *San Francisco Bay* | *San Pablo Bay Carquinez Strait* | *Suisun Bay* | *Sacramento-San Joaquin Delta* | *Sacramento & American Rivers* | *Upper Sacramento & Feather Rivers* | *San Joaquin River* |
| 1969 | 2.9 | 39.7 | 24.6 | 5.2 | 16.0 | 8.2 | 2.9 | 0.5 |
| 1970 | 2.0 | 38.8 | 26.4 | 4.6 | 17.9 | 7.3 | 2.4 | 0.6 |
| 1971 | 0.2 | 29.8 | 24.1 | 5.2 | 18.9 | 11.0 | 10.0 | 0.9 |
| 1972 | 2.4 | 40.3 | 18.9 | 7.1 | 17.1 | 6.4 | 7.5 | 0.3 |
| 1973 | 2.8 | 45.2 | 17.3 | 2.9 | 13.8 | 7.0 | 10.2 | 0.8 |
| 1974 | 1.5 | 54.0 | 17.3 | 3.1 | 12.6 | 2.9 | 8.3 | 0.4 |
| 1975 | 0.6 | 30.9 | 21.2 | 2.5 | 20.5 | 10.0 | 14.1 | 0.3 |
| 1976 | 2.1 | 26.2 | 23.2 | 7.4 | 26.0 | 6.0 | 8.8 | 0.3 |
| 1977 | 8.4 | 25.1 | 18.8 | 6.6 | 24.0 | 8.0 | 9.0 | 0.0 |
| 1978 | 0.8 | 35.0 | 16.9 | 10.1 | 22.8 | 10.1 | 4.2 | 0.0 |
| 1979 | 1.3 | 19.7 | 21.7 | 11.9 | 28.2 | 6.9 | 9.3 | 1.1 |
| Mean | 2.3 | 35.0 | 21.0 | 6.1 | 19.8 | 7.6 | 7.9 | 0.5 |
| SE | 0.67 | 2.99 | 1.00 | 0.90 | 1.51 | 0.68 | 1.05 | 0.11 |

On the average, private boat, shore, and charter boat anglers accounted for about 65%, 21%, and 14% of the annual catch, respectively (Figure 4). There was a statistically significant ($t = 4.45$, $P < 0.005$) upward trend in shore anglers' share of the catch from 1969 to 1979. The fraction of the catch taken on charter boats and private boats did not significantly increase or decrease over the years ($t = 0.06$, $P > 0.90$ and $t = 2.22$, $P > 0.05$, respectively).

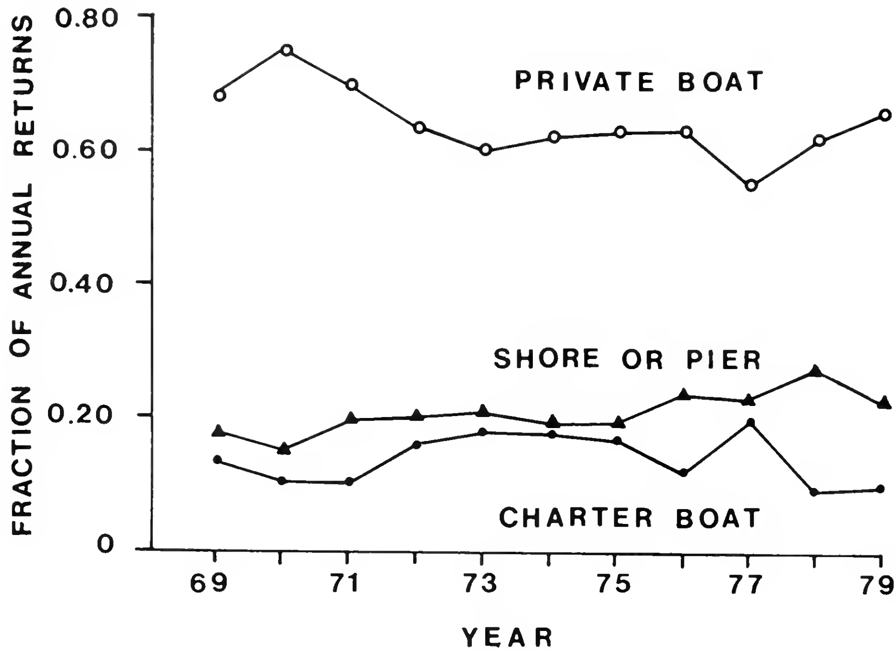


FIGURE 4. Proportion of annual catch of striped bass in the Sacramento-San Joaquin Estuary taken from private boats, charter boats, and shore or pier. Calculated using all tags returned, including first year returns of nonreward tags (creel and response-corrected mail returns), reward tags, and tags applied in previous years.

## Length, Age, and Sex Composition of Catch

The mean fork length (FL) of bass measured in the creel census from 1969 to 1979 was 65.1 cm and ranged from 57.8 cm in 1979 to 72.0 cm in 1977 (Table 4).

Mean length varied with fishing location. Bass caught in the Pacific Ocean averaged 80.0 cm FL and were consistently larger than those from other areas (Figure 5). On the average, bass caught in Carquinez Strait and Suisun Bay were the smallest (51.5 cm). Fish from San Francisco Bay and San Pablo Bay were intermediate in length, averaging 64.6 cm and 65.4 cm, respectively.

Fish length decreased significantly from 1969 to 1979 in all areas (Pacific Ocean; $t = 3.27$, $P < 0.01$; San Francisco Bay: $t = 2.51$, $P < 0.05$; San Pablo Bay: $t = 5.43$, $P < 0.001$; Carquinez Strait-Suisun Bay: $t = 2.43$, $P < 0.05$).

**TABLE 4. Mean Fork Length (FL) in Centimeters, Standard Error (SE), and Number of Striped Bass Measured (n) During the Creel Census in the Sacramento-San Joaquin Estuary. Private Boat and Shore Angler Catches Were Not Sampled in 1977 and 1978. Standard Error Was Calculated as Standard Deviation of Month-Area Sample Means.**

| Year | Private boat | | | Charter boat | | | Shore | | | TOTAL | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $\hat{FL}$,cm | SE | n | $\hat{FL}$,cm | SE | n | $\hat{FL}$,cm | SE | n | $\hat{FL}$,cm | SE | n |
| 1969 | 70.4 | 14.56 | 6,466 | 67.8 | 11.36 | 3,591 | 60.5 | 10.43 | 60 | 69.5 | 11.70 | 10,117 |
| 1970 | 68.0 | 11.65 | 6,779 | 62.3 | 10.67 | 3,807 | 69.0 | – | 1 | 65.9 | 10.74 | 10,587 |
| 1971 | 68.1 | 11.55 | 8,468 | 62.0 | 9.42 | 4,764 | 65.8 | 15.26 | 6 | 65.9 | 10.14 | 13,238 |
| 1972 | 64.6 | 11.19 | 10,477 | 61.0 | 12.14 | 12,364 | 66.6 | 14.20 | 69 | 62.7 | 11.67 | 22,910 |
| 1973 | 69.8 | 13.00 | 8,070 | 66.9 | 12.76 | 12,559 | 57.8 | 21.95 | 52 | 68.0 | 12.95 | 20,681 |
| 1974 | 66.7 | 15.14 | 12,713 | 61.4 | 11.30 | 20,696 | 76.9 | 20.90 | 19 | 63.5 | 11.31 | 33,428 |
| 1975 | 66.5 | 12.09 | 9,253 | 63.3 | 13.45 | 17,107 | 61.1 | 13.98 | 57 | 64.5 | 12.56 | 26,417 |
| 1976 | 64.0 | 12.82 | 8,098 | 63.5 | 14.75 | 12,227 | 66.3 | 14.88 | 14 | 63.7 | 14.95 | 20,339 |
| 1977 | – | – | 0 | 72.0 | 11.89 | 4,073 | – | – | 0 | 72.0 | 11.89 | 4,073 |
| 1978 | – | – | 0 | 62.9 | 11.09 | 1,441 | – | – | 0 | 62.9 | 11.09 | 1,441 |
| 1979 | 61.1 | 12.34 | 1,300 | 57.1 | 10.14 | 6,037 | 57.3 | 11.01 | 14 | 57.8 | 11.67 | 7,351 |
| 1969–1979 Mean | | | | 63.7 | | | | | | 65.1 | | |
| Standard Deviation | | | | 3.97 | | | | | | 3.81 | | |
| 1969–76, 79 Mean | 66.6 | | | 62.8 | | | 64.6 | | | | | |
| Standard Deviation | 2.96 | | | 3.18 | | | 6.20 | | | | | |

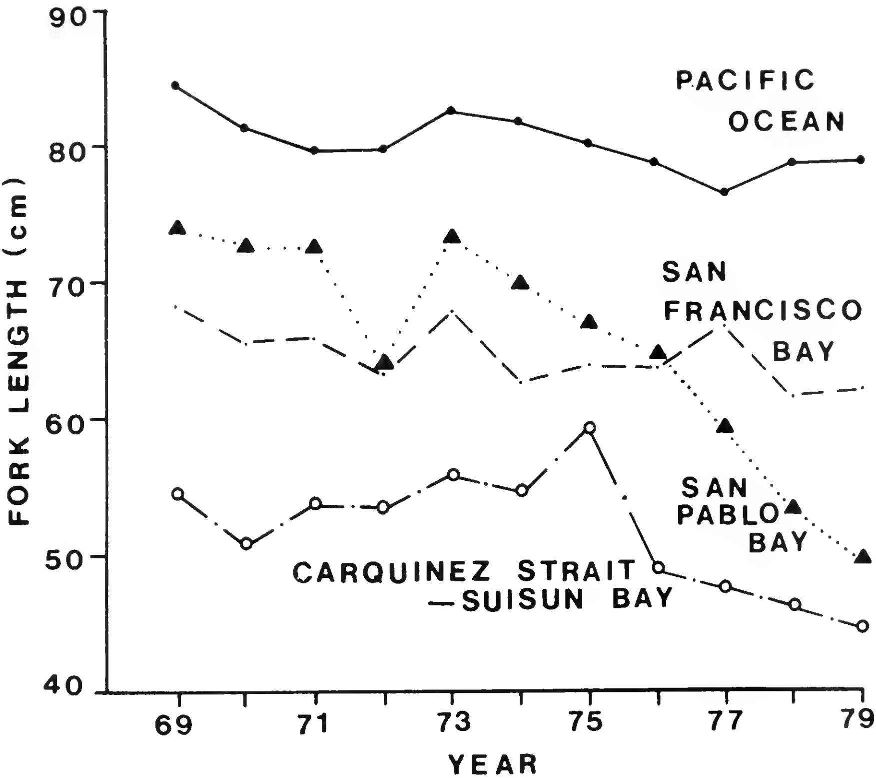


FIGURE 5. Annual mean fork length of striped bass caught in four areas of the western Sacramento-San Joaquin Estuary.

Anglers on private boats consistently caught larger fish than anglers on charter boats ($t = 2.62$, $P < 0.05$; Table 4). The overall difference was due to a consistent difference in San Pablo Bay and Carquinez Strait-Suisun Bay (Figure 6). In the Pacific Ocean, bass caught on private boats and charter boats were of similar size in most years; in San Francisco Bay, bass caught on private boats were larger through 1975 and smaller thereafter.

The average bass caught from shore appeared to be intermediate in size between those caught on the two types of boats, although samples of shore caught fish were small and lengths were rather variable (Table 4).

From 1969 to 1979, almost two-thirds of the censused catch was comprised of 3, 4, and 5 year old bass (Figure 7). Overall, 4-year-old fish were the most abundant age group in the catch and each successively older age group became less abundant. Two-year-old bass accounted for less than 1% of the catch.

Within individual years, the age composition often deviated from the average pattern (Figure 7). Age 3 bass were well underrepresented in 1969 (11%), 1973 (10%), and 1977 ($<$8%) compared to the 11 year average of about 21%. Hence, other age classes were relatively more numerous in these years. In 1969, age 7 and older bass formed 39% of the catch (11 year average: 22%). The 1973 catch had a high proportion of ages 4–6 (68% compared to the 56% average). In 1977, 5–8 year old bass accounted for 71% of the catch (average of 46%).

Conversely, the age composition in 1979 was unusual as 3 year old bass from the 1976 year class made up almost half the catch, the result of good trolling during summer evenings in Carquinez Strait. The percentage of old (age $\geq 8$) fish declined noticeably during the early 1970's and remained low except in 1977 when fishing was good in the ocean.

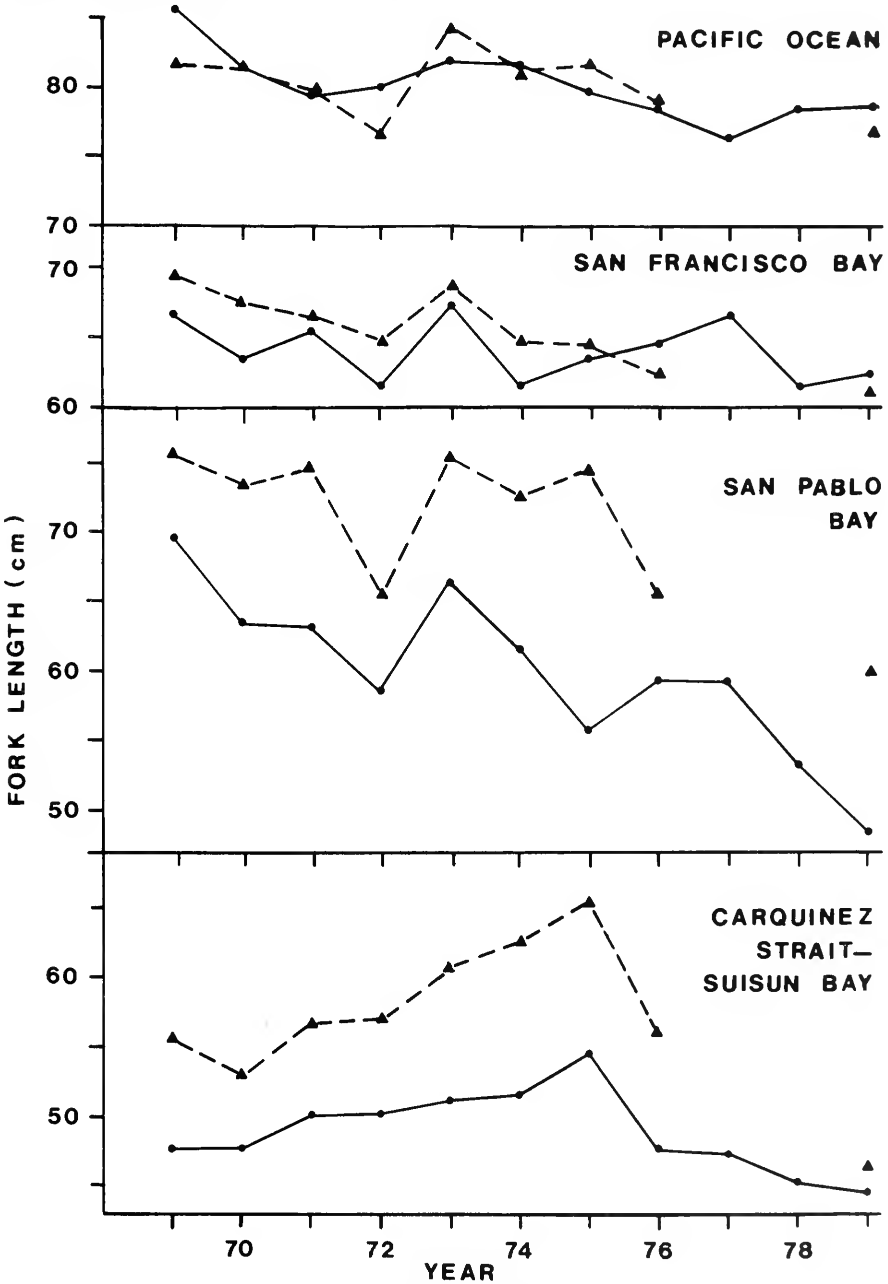


FIGURE 6. Annual mean fork length of striped bass caught by charter boat (•) and private boat (▲) anglers in four areas of the western Sacramento-San Joaquin Estuary. Private boat catch not sampled in 1977 and 1978.

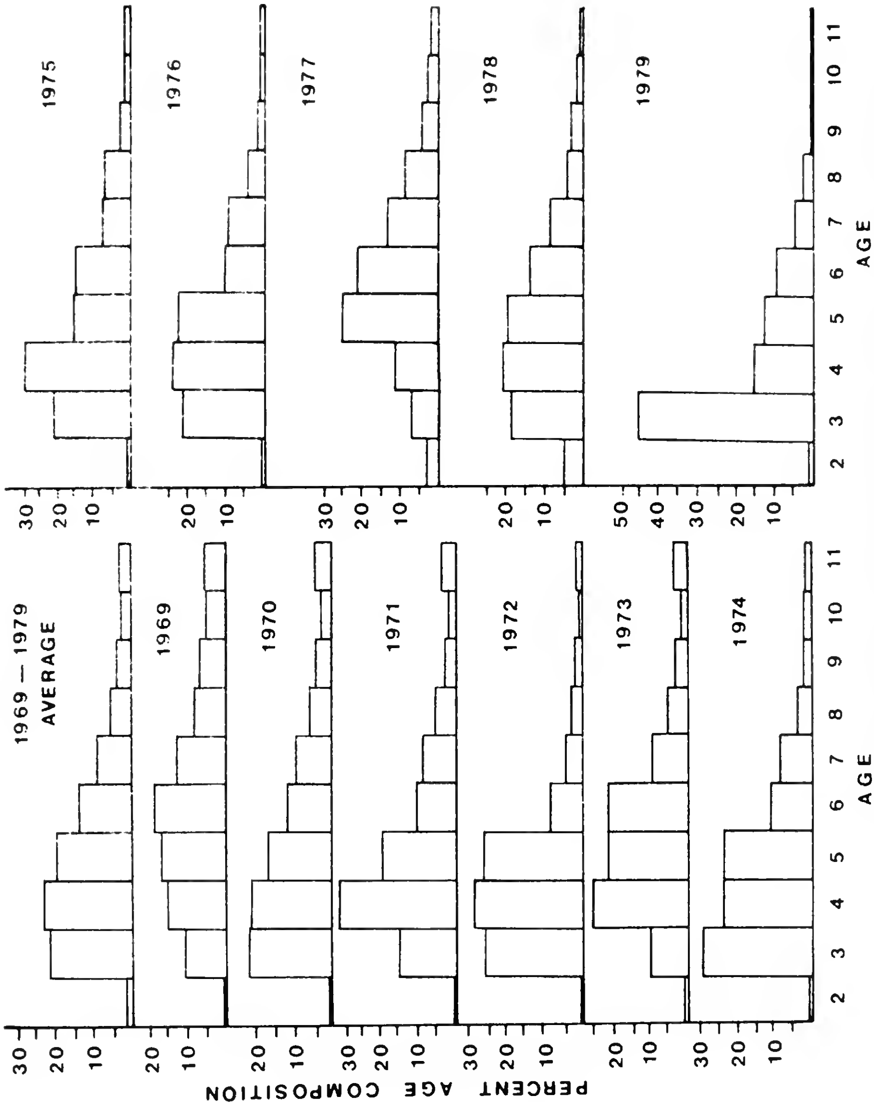


FIGURE 7. Annual age composition of the striped bass catch sampled in the San Francisco Bay area creel census, including 1969–1979 average.

Significantly more female than male striped bass were observed in the catch every year except in 1979 when more males were seen (Table 5). Percent females averaged 55.5% and ranged from 63.5% of the catch in 1977 to 48.3% in 1979. For the years during which both charter boat and private boat catches were censused, percent females in the private boat catch (55.4%) was significantly greater than in the charter boat catch (53.1%) ($t = 9.93$, $P < 0.001$).

**TABLE 5. Percent Female Striped Bass in the San Francisco Bay Area Catch, with Results of Chi-Square Tests of the Hypothesis for all Fishing Methods that Number Males = Number Females.**

| Year | ALL METHODS % Female | ALL METHODS Bass Sexed | $X^2$ | $P <$ | CHARTER BOATS % Female | PRIVATE BOATS % Female |
|---|---|---|---|---|---|---|
| 1969 | 58.6 | 9,075 | 265.7 | 0.001 | 55.9 | 60.2 |
| 1970 | 55.8 | 9,121 | 123.8 | 0.001 | 53.4 | 57.3 |
| 1971 | 56.7 | 12,131 | 219.8 | 0.001 | 56.0 | 57.2 |
| 1972 | 51.5 | 21,227 | 19.5 | 0.001 | 51.1 | 51.9 |
| 1973 | 55.1 | 16,879 | 227.1 | 0.001 | 54.7 | 55.7 |
| 1974 | 51.5 | 29,329 | 27.7 | 0.001 | 49.9 | 54.1 |
| 1975 | 54.9 | 24,241 | 235.1 | 0.001 | 55.3 | 54.3 |
| 1976 | 54.5 | 19,249 | 153.2 | 0.001 | 53.6 | 55.8 |
| 1977 [1] | 63.5 | 3,931 | 277.4 | 0.001 | (63.5) | |
| 1978 [1] | 59.6 | 1,291 | 48.0 | 0.001 | (59.6) | - |
| 1979 | 48.3 | 7,004 | 8.2 | 0.005 | 47.6 | 51.8 |
| Mean | 55.5 | | 1,045.3 | 0.001 | 53.1 | 55.4 |
| Standard Deviation | 4.21 | | | | 2.93 | 2.70 |

[1] Charter boat census was reduced and private boat census eliminated in 1977 and 1978. These years omitted from the mean values for charter boats and private boats.

On a monthly basis, exceptions to domination of the catch by females occurred mostly during June (Table 6). In 1979 when males were dominant, there were significantly more males than females caught in June and August. That year females prevailed in only two months, July and December, and then differences were small.

**TABLE 6. Results of Chi-Square Tests of the Sex Ratio in the Striped Bass Catch Observed in the San Francisco Bay Area. F or f Indicates More Females; M or m Indicates More Males; =, Equal Numbers of Each Sex. Upper Case Letters Denote Statistically Significant Difference at $\alpha = 0.05$.**

| Year | Jun | Jul | Aug | Sept | Oct | Nov | Dec | Total |
|---|---|---|---|---|---|---|---|---|
| 1969 | F | F | F | F | F | F | F | F |
| 1970 | m | F | F | F | F | F | F | F |
| 1971 | f | F | F | F | F | F | F | F |
| 1972 | m | F | F | F | F | F | F | F |
| 1973 | F | F | F | M | F | F | F | F |
| 1974 | f | F | F | f | m | F | F | F |
| 1975 | M | F | F | F | F | F | F | F |
| 1976 | m | F | F | F | F | f | F | F |
| 1977 | f | F | F | F | f | F | m | F |
| 1978 | m | F | F | F | f | m | [1] | f |
| 1979 | M | f | M | m | m | = | f | M |

[1] No data.

## Fishing Effort and Success

Approximately 1.4 million angler hours were recorded by the creel census from 1969–1979. Effort covered by our sample interviews ranged from about 54,000 angler hours in 1979 to almost 200,000 angler hours in 1969 and 1974 (Figure 8). Interviewed effort on private boats declined from about 120,000 angler hours in 1969 to about 15,000 angler hours in 1979 and this trend was statistically significant ($t = 4.36$, $P < 0.05$, no data for 1977 and 1978). Charter boat effort fluctuated irregularly from 1969 to 1979 with no consistent trend (data from reduced census in 1977 and 1978 excluded). However, as for private boats, the lowest effort was in 1979 and it was less than half of the peak effort in 1974, only 5 years earlier. While my data represent an unknown portion of the total fishing effort, I believe these trends are valid since census effort was about equal each year.

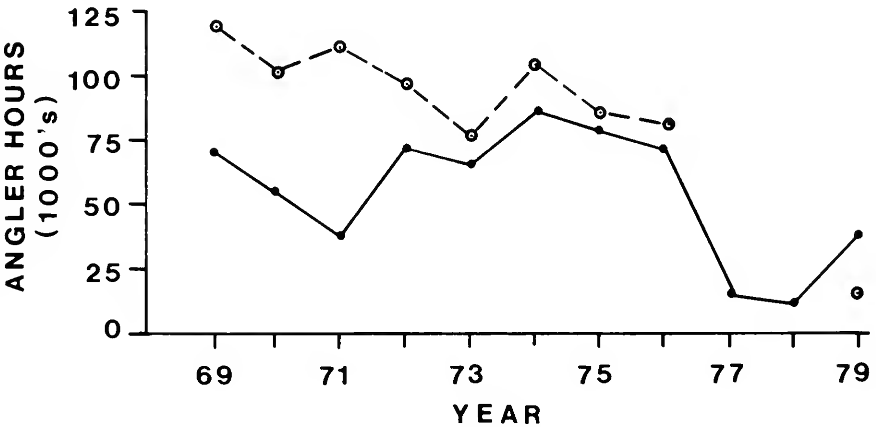


FIGURE 8. Fishing effort by charter boat (•) and private boat (◉) striped bass anglers sampled in the San Francisco Bay area creel census. Private boats were not sampled and charter boat sampling effort was reduced by 75–80% in 1977 and 1978.

Angler success (bass/angler h) was estimated from the censused effort and catch. These estimates of success are biased upward slightly because the census was designed primarily to gather data for estimating striped bass abundance. Therefore when several boats landed simultaneously, samplers selected the boats with the largest catches.

Success was highly variable from 1969–1979 (Figure 9). From 0.10 bass/angler h in 1969–1971, overall success increased substantially, averaging 0.18 bass/angler h from 1972 to 1974. Success declined in 1975 and 1976. Only charter boats were censused in 1977 and 1978, and their success was high in 1977 (0.27 bass/angler h) and low (0.11 bass/angler h) in 1978. In 1979 overall success (0.14 bass/angler h) was about the same as in 1976 and nearly equal to the 1969–1976 average.

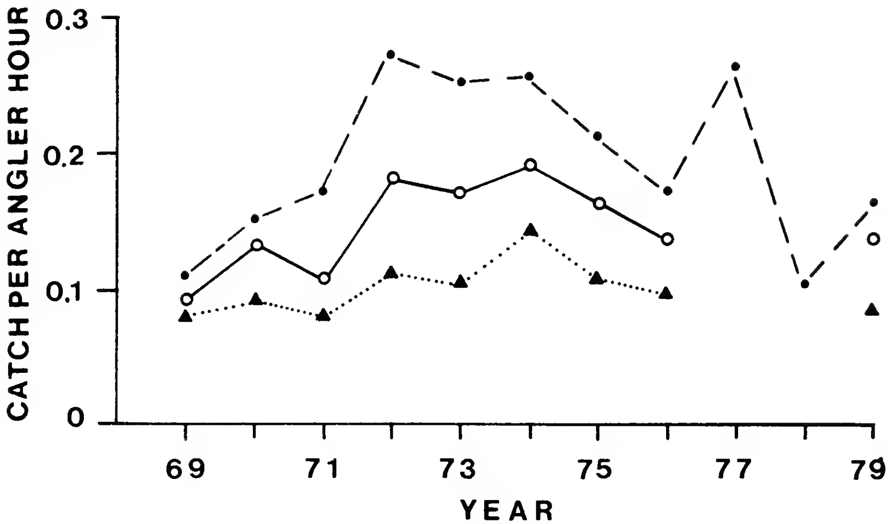


FIGURE 9. Striped bass angler success on charter boats (•) and private boats (▲) and both combined (○) in the San Francisco Bay Area. Private boats were not sampled in 1977 and 1978.

Mean charter boat angler success (0.20 bass/angler h) was twice that of private boat anglers (0.10 bass/angler h). Annual variation in success also was greater for charter boats than for private boats (F = 8.84, $P < 0.01$). Charter boat success ranged from 0.11 (1969, 1978) to 0.28 (1972) bass/angler h compared to a range of 0.08 (1969, 1979) to 0.17 (1974) bass/angler h for private boats. Based on the 9 years for which comparative data were obtained, the difference between the success of charter boat and private boat anglers was statistically significant (t = 4.62, $P < 0.001$). Despite these differences, charter boat and private boat success were significantly correlated (r = 0.83, $P < 0.01$).

After analysis of variance revealed that angler success differed significantly among areas (charter boats: F = 8.65, $P < 0.001$; private boats: F = 17.16, $P < 0.001$), an *a posteriori* stepwise range test (Student-Newman-Keuls test, Sokal and Rohlf 1969) was used to determine that charter boat anglers were significantly more successful ($P < 0.01$) in San Francisco Bay than in the Pacific Ocean, San Pablo Bay, or Carquinez Strait-Suisun Bay (Table 7). For private boats, angler success was similar in the ocean, San Francisco Bay, and Carquinez Strait-Suisun Bay, but in San Pablo Bay success was significantly lower ($P < 0.05$).

Except for 1977, when fishing was exceptionally good in the ocean, summer success was similar in all years. Overall success varied annually primarily due to differences in fall fishing (Figure 10).

## DISCUSSION

My results show declines in the annual striped bass catch and angling effort, in regions creel censused, during the mid- to late-1970's. However, a more general decline in the fishery actually has occurred since 1958 (Stevens et al.

1985). It is attributable to a decline in bass abundance which apparently is due to: (i) reduced recruitment explained by a decline in the abundance of young bass and (ii) increased mortality of adults resulting from the increased harvest rates in the mid-1970's.

**TABLE 7. Mean Angler Success (Bass/Angler h) of Charter Boat and Private Boat Anglers in the San Francisco Bay Area Striped Bass Fishery. Private Boat Anglers Were Not Sampled in 1977 and 1978.**

| *CHARTER BOAT* | *FISHING AREAS* | | | |
|---|---|---|---|---|
| *Year* | *Pacific Ocean* | *San Francisco Bay* | *San Pablo Bay* | *Carquinez Strait Suisun Bay* |
| 1969 | 0.096 | 0.141 | 0.051 | 0.052 |
| 1970 | 0.087 | 0.219 | 0.071 | 0.053 |
| 1971 | 0.059 | 0.234 | 0.051 | 0.156 |
| 1972 | 0.213 | 0.361 | 0.098 | 0.162 |
| 1973 | 0.150 | 0.315 | 0.066 | 0.113 |
| 1974 | 0.100 | 0.305 | 0.089 | 0.157 |
| 1975 | 0.183 | 0.241 | 0.124 | 0.071 |
| 1976 | 0.215 | 0.173 | 0.126 | 0.225 |
| 1977 | 0.381 | 0.179 | 0.118 | 0.153 |
| 1978 | 0.097 | 0.100 | 0.123 | 0.040 |
| 1979 | 0.097 | 0.165 | 0.107 | 0.237 |
| 69–76, 79 Mean | 0.133 | 0.239 | 0.087 | 0.136 |
| Standard Deviation | 0.0587 | 0.0749 | 0.0289 | 0.0692 |
| 69–79 Mean | 0.153 | 0.221 | 0.093 | 0.129 |
| Standard Deviation | 0.0927 | 0.0802 | 0.0292 | 0.0688 |

| *PRIVATE BOAT* | | | | |
|---|---|---|---|---|
| *Year* | *Pacific Ocean* | *San Francisco Bay* | *San Pablo Bay* | *Carquinez Strait Suisun Bay* |
| 1969 | 0.178 | 0.137 | 0.048 | 0.101 |
| 1970 | 0.127 | 0.171 | 0.056 | 0.208 |
| 1971 | 0.153 | 0.154 | 0.044 | 0.161 |
| 1972 | 0.145 | 0.168 | 0.068 | 0.176 |
| 1973 | 0.178 | 0.154 | 0.053 | 0.108 |
| 1974 | 0.030 | 0.190 | 0.072 | 0.105 |
| 1975 | 0.033 | 0.131 | 0.070 | 0.190 |
| 1976 | 0.070 | 0.091 | 0.101 | 0.169 |
| 1977 | – | – | – | – |
| 1978 | – | – | – | – |
| 1979 | 0.032 | 0.086 | 0.045 | 0.086 |
| 69–76, 79 Mean | 0.110 | 0.142 | 0.062 | 0.144 |
| Standard Deviation | 0.0623 | 0.0353 | 0.0182 | 0.0443 |

The decline in striped bass abundance indicates that mortality is exceeding recruitment (Stevens et al. 1985); yet harvest rates, a major component of total mortality, for 1969–1979 are within the range of estimates reported by Chadwick (1968) and Miller (1974) for 1958–1971. Also, peak harvest rates of about 27% in the mid-1970's are lower than exploitation of Atlantic coast stocks (Kohlenstein 1981) which are fished both for sport and commercially.

I examined the possibility that our harvest rates were underestimated due to anglers not returning reward tags. To do this, I re-estimated the harvest rates by (i) extrapolating charter boat catches reported on logs [Stevens 1977*b* and unpublished; adjusted for inaccuracies and nonreporting (Grant 1977)] to total catch based on the percent of annual catch by charter boats (Figure 4), and (ii) dividing these total catch estimates by the Petersen population estimates (Table 2). These harvest rate estimates are independent of angler response, but averaged 45% lower than the estimates based on tag returns. Thus, these results did not provide evidence that the initial harvest rates were underestimated. The lower re-estimated harvest rates probably are due to error in the charter boat catch adjustments (Grant 1977) and/or the Petersen estimates of abundance (Stevens 1977*a*, Stevens et al. 1985).

My annual catch estimates (Table 2) are minimum estimates because striped bass abundance estimates used in the calculation pertain to the number of legal size fish in the spring when only about half of the 3 year old bass are legal size. The remaining 3-year-olds are recruited during the summer but are not included in the catch estimate.

Catches are influenced by the amount of striped bass fishing effort—declining catches are accentuated by the tendency for anglers to fish less when fishing is poor. For example, the amount of angler effort on charter boats is directly related to angler success (Miller 1974). While my creel census data does not reveal a

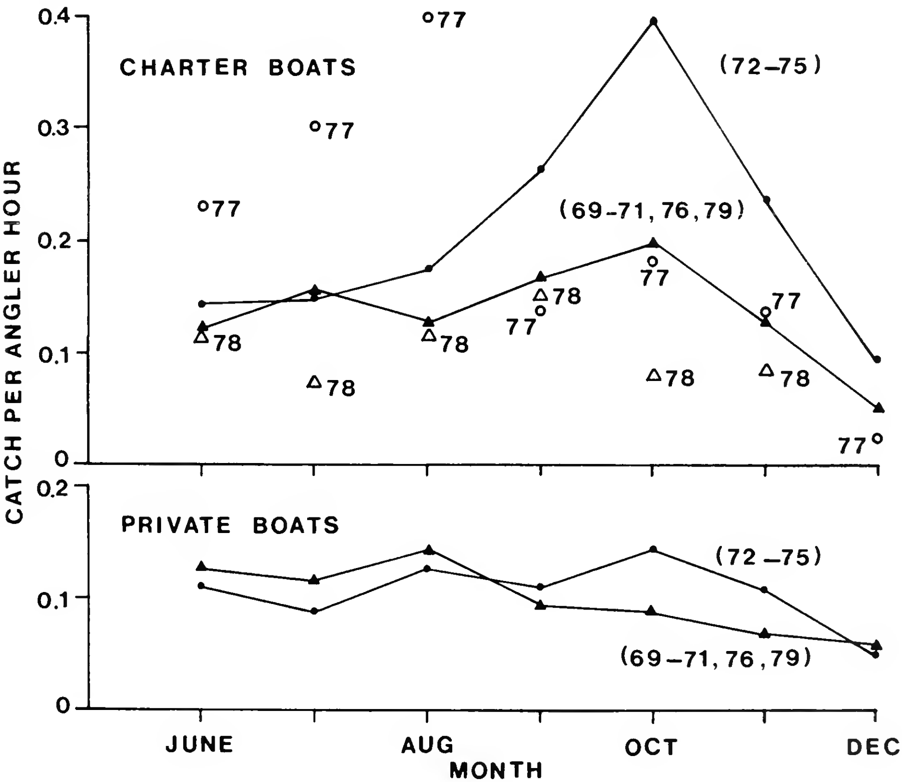


FIGURE 10. Monthly striped bass fishing success in years when success was high (1972–1979) (•) and in years when success was lower (1969–1971, 1976, 1979) (▲) for charter boats and private boats in the San Francisco Bay area. Charter boat success in 1977 and 1978 is plotted separately; private boats were not sampled in 1977 and 1978.

statistically significant correlation between effort and success, it does provide evidence that effort was reduced by low success. After a disastrous season in 1978, many charter boats in San Francisco Bay responded to declining angler interest by shifting a major portion of their effort from striped bass to California halibut, *Paralichthys californicus,* and rockfish (*Sebastes* sp.). This "potluck" strategy contributed to San Francisco Bay providing its lowest percentage of the total annual striped bass catch in 1979 (Table 3).

The seasonality of the striped bass catch is influenced by their migrations and feeding activity. Catches increase in the spring when bass occur in high densities on the spawning grounds and thus attract anglers. However, their vulnerability does not peak then because their feeding is diminished (Stevens 1966). The greatest catches generally occur during the summer and fall in San Francisco and San Pablo bays when the bass feed more actively. Catches are lowest during winter because fishing effort is reduced by inclement weather, the bass are widely scattered (Chadwick 1967, Orsi 1971), the water is turbid, and fish metabolism is low due to low water temperature.

Catches differ geographically each year, apparently due to changes in migrations and environmental conditions. For example, a drought in 1976–1977 reduced freshwater flows resulting in increased salinity intrusion and high water transparency in the Delta and Suisun Bay in fall and winter. Similar conditions existed in fall-winter, 1978 and fall, 1979 as significant precipitation did not occur until late in those seasons. Tag returns from both areas increased beginning in 1976 (Table 3). Salinity intrusion may have induced more bass to migrate from San Francisco Bay to Suisun Bay and the Delta in the fall as suggested by a negative, although not statistically significant, correlation ($r = -0.42$) between Suisun Bay-Delta returns (percent of annual releases) and returns from San Francisco Bay. Also, clear water may have enhanced fishing as the tag return rate is positively correlated with water transparency (Figure 11).

The mean length of bass in the population declined during the 1970's (Table 4). Apparently the strong year classes of the late 1950's (Stevens 1977*b*) which provided good fishing for large bass in the late 1960's and early 1970's were dying out. Since subsequent year classes were weaker, the abundance of large bass declined. In the mid 1970's, there probably were several moderate year classes (Stevens et al. 1985) which were subjected to increasing harvest rates when recruited. This higher mortality would have further reduced the abundance of large bass in subsequent years. The decline in average size continued in the late 1970's in spite of consistently low recruitment since 1976 (Stevens et al. 1985).

Considering the downward trend in mean size, the high harvest of large bass in the Pacific Ocean in 1977 is anomalous. Apparently they were more vulnerable than usual that year. I found that these catches were not consistent with Radovich's (1963) hypothesis of warm sea temperatures inducing seaward migrations and higher ocean catches of striped bass. Some of the lowest ocean catches occurred in 1974, 1975, and 1978 when summer ocean temperatures at Hopkins Marine Station, Pacific Grove, CA were similar to 1977 (June–August mean:14.1–14.3°C). Ocean catches were only average in 1972 and 1976 when summer ocean temperatures were higher (14.9–15.0°C). Possibly, forage fish were abundant in the surf zone which concentrated the bass so they were available to anglers in 1977. However, this explanation cannot be tested with available data.

The high ocean harvest in 1977 may have been detrimental. It consisted of a high proportion of females (63.5%) which contributed to a high overall harvest (28.3%) of females 5 years and older. These fish account for almost all striped bass egg production which currently may be inadequate in this population (Stevens et al. 1985).

In the San Pablo-Suisun Bay region, private boat anglers caught much larger bass, on average, than charter boat anglers (Figure 6). This difference reflects private boats fishing extensively with bait for large bass in fall and winter, but relatively few of them fishing during summer evenings when charter boats are trolling for smaller bass.

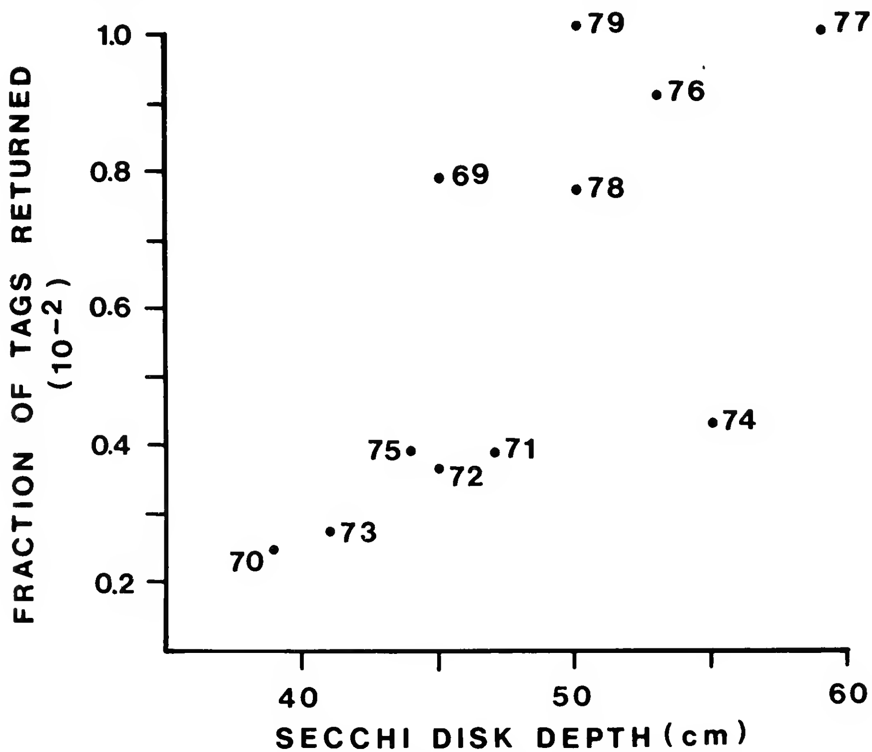


FIGURE 11. Scatter plot of 1st year tag returns from Suisun Bay and the Delta (mean of Oct., Nov., and Dec. returns as a percentage of tags released) and water transparency. December tag returns were not used for 1973–1979 because transparency data for December were incomplete. Correlation coefficient = 0.76 ($p \angle 0.01$) after arcsin transformation of decimal fractions.

The age composition of the catch varied annually but was particularly unusual in 1979. Age 3 bass (1976 year class) comprised an abnormally high 45% of the bay area catch that year (Figure 7), even though when young, their abundance was among the lowest of the year classes recruited during the 1969–1979 census (Stevens et al. 1985). Possible explanations are: (i) High vulnerability for age 3 bass in 1979—catches were high in the Carquinez Strait evening troll fishery. These bass may have found abundant forage and remained in the Strait through the summer. Angler success was high (0.24 bass/angler h) and anglers responded by increasing effort. (ii) Low abundance of older bass due to only moderate recruitment in the early 1970's and high mortality in the mid-1970's (Stevens et al. 1985) skewing the 1979 age composition toward the new recruits. (iii) High survival between ages 0 and 3 for the 1976 year class. These explanations will be evaluated as appropriate data become available.

More female than male bass were censused every year except 1979. The system-wide harvest rate is highly variable and there is no consistent pattern favoring either sex. In the Bay area apparently females are more abundant than males during the census season. Males dominated the censused catch in 1979 because of the exceptional evening trolling in the summer which exploited small males returning from spawning.

Angler success during 1969–1979 generally was lower than in 1960 and 1961 (Chadwick and Albrecht 1965) when bass were more abundant (Stevens et al. 1985). Differences between charter boat and private boat success and between success in San Francisco and San Pablo bays were similar to 1960–1961.

On average, charter boat anglers were twice as successful as private boat anglers, primarily because charter boat operators are skilled at fishing and know the productive locations. Average angler success also varies more both seasonally and annually on charter boats than on private boats. While some private boat anglers are as skilled as charter boat operators, many are inexperienced and fish only occasionally, primarily when they hear good reports. Thus, good fishing results in increased effort on both charter boats and private boats, but average catch/angler h increases less on private boats causing less variable success statistics.

## ACKNOWLEDGMENTS

Recognition is due to the many Department of Fish and Game employees who contributed to the striped bass tagging program, the creel census, and the processing of tag returns through the years. J. Bybee, R. Rogers and J. Grant supervised the creel census crews through 1977. I thank B. Collins for suggestions regarding statistical analyses and D. Stevens, D. Kohlhorst and H. Chadwick for their critical reviews of this manuscript. K. Odenweller drew the figures. This work was performed as part of Dingell-Johnson Project F-9-R, "A Study of Sturgeon, Striped Bass, and Resident Fishes" supported by Federal Aid to Fish Restoration Funds.

## LITERATURE CITED

Bailey, N. J. J. 1951. On estimating the size of mobile populations from recapture data. Biometrika, 38:293–306.

Chadwick, H. K. 1967. Recent migrations of the Sacramento-San Joaquin striped bass population. Am. Fish. Soc., Trans., 96(3):327–342.

________ 1968. Mortality rates in the California striped bass population. Calif. Fish Game, 54(4):228–246.

Chadwick, H. K., and A. B. Albrecht. 1965. The summer and fall striped bass fishery during 1960 and 1961. Calif. Dept. Fish and Game, Inland Fish. Br. Admin. Rept. No. 65-11. 27 pp.

Grant, J. J. 1977. Evaluation of striped bass party boat log reporting for the Sacramento-San Joaquin Estuary from 1969 to 1974. Calif. Fish Game Anad. Fish. Br. Admin. Rept. No. 77-8. 20 pp.

Kohlenstein, L. C. 1981. On the proportion of the Chesapeake Bay stock of striped bass that migrates into the coastal fishery. Am. Fish. Soc., Trans., 110(1):168–179.

Miller, L. W. 1974. Mortality rates for California striped bass (*Morone saxatilis*) from 1965–1971. Calif. Fish Game, 60(4):157–171.

Orsi, J. J. 1971. The 1965–1967 migrations of the Sacramento-San Joaquin Estuary striped bass population. Calif. Fish Game, 57(1):257–267.

Radovich, J. 1963. Effect of ocean temperature on the seaward movements of striped bass, *Roccus saxatilis,* on the Pacific coast. Calif. Fish Game. 49(3):191–206.

Sokal, R. R., and F. J. Rohlf. 1969. Biometry. W. H. Freeman and Co. 776 pp.

Stevens, D. E. 1966. Food habits of striped bass, *Roccus saxatilis,* in the Sacramento-San Joaquin Delta. Calif. Dept. Fish and Game, Fish. Bull. (136) 68–96.

Stevens, D. E. 1977*a*. Striped bass (*Morone saxatilis*) monitoring techniques in the Sacramento-San Joaquin Estuary. Pages 91–109. *in:* W. Van Winkle, ed. Proc. of the Conf. on Assessing the Effects of Power-Plant-Induced Mortality on Fish Populations. Pergamon Press, Inc., New York.

———. 1977*b*. Striped bass (*Morone saxatilis*) year class strength in relation to river flow in the Sacramento-San Joaquin Estuary, California. Am. Fish. Soc., Trans., 106(1):34–42.

Stevens, D. E., D. W. Kohlhorst, L. W. Miller and D. W. Kelley. 1985. The decline of striped bass in the Sacramento-San Joaquin Estuary. Am. Fish. Soc., Trans., 114(1):12–30.

*Calif. Fish and Game* 72(1): 38–46 1986

# FOOD OF JUVENILE CHINOOK, *ONCORHYNCHUS TSHAWYTSCHA,* AND COHO, *O. KISUTCH,* SALMON OFF THE NORTHERN OREGON AND SOUTHERN WASHINGTON COASTS, MAY–SEPTEMBER 1980 [1]

ROBERT L. EMMETT, DAVID R. MILLER, and THEODORE H. BLAHM
Coastal Zone and Estuarine Studies Division
Northwest and Alaska Fisheries Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
2725 Montlake Boulevard East
Seattle, Washington 98112

**The food of juvenile chinook, *Oncorhynchus tshawytscha,* and coho, *O. kisutch,* salmon captured in the northern Oregon and southern Washington coastal zones during three cruises, May-September 1980, is described. Fishes were primary prey for both species during the first cruise. Although diets overlapped, fishes and crab larvae were primary prey for chinook salmon in the second cruise, while fishes and the euphausiid *Thysanoessa spinifera* were important prey for coho salmon. During the third cruise, hyperiid amphipods were primary prey for both species. There were relatively few empty stomachs during any cruise. Fullness values are used to discuss possible food limitations.**

## INTRODUCTION

Individuals and resource agencies interested in the perpetuation of Pacific salmon, *Oncorhynchus* spp., in the Pacific Northwest are becoming more aware of the need to understand the ecology of salmon in the marine environment. Fewer adult returns of coho salmon, *O. kisutch,* even though hatchery production has been increasing, has recently stimulated interest in this species habits (Gunsolus 1978). Biologists have concluded that reduced upwelling off the Pacific Northwest coast has lowered primary production and thus the carrying capacity for salmonids (Oregon Department of Fish and Wildlife 1982).

Adequate early marine feeding is apparently a critical factor in determining the resultant number of adult salmon returns (Healey 1980), and yet there are only limited data concerning the food of juvenile salmon in marine waters. Previous food studies of salmonids in coastal waters of Oregon and Washington (Reimers 1964) and other Pacific areas (Silliman 1941, Merkel 1957, Andrievskaya 1957, Allen and Aron 1958, Ito 1964, LeBrasseur 1966) have been concerned primarily with adults. Recently, Healey (1978, 1980) described the food habits of juvenile chinook, *O. tshawytscha,* and coho salmon collected in British Columbia marine waters during spring and summer. Peterson, Brodeur and Pearcy (1983) presented food habit data of juvenile chinook and coho salmon captured in coastal waters of Oregon and southern Washington in June 1979.

This paper provides additional information on the feeding of juvenile salmon in the coastal waters of northern Oregon and southern Washington during the spring and summer of 1980.

## METHODS

Fishes for this study were collected with a purse seine (495 x 30 m) from 10

[1] Accepted for publication March 1985.

five-station, east-west transects between Tillamook Bay, Oregon, and Copalis Head, Washington, (Figure 1). The net was constructed of 32-mm knotted nylon web with 30 meshes of 127-mm nylon hung along the bottom above the lead line. The bunt was made of 18-mm knotted nylon web. Three cruises were conducted beginning 27 May 1980, 4 July 1980, and 28 August 1980; one day of sampling time was allotted per transect during each cruise. Descriptions of the sampling vessel, equipment, water quality measurements, fish processing, and overall catch, along with distribution, abundance, and growth of juvenile salmonids during the cruises can be found in Miller, Williams, and Sims (1983).

The first 10 individuals of each species (if available) from each seine set were taken for stomach analysis. All salmonids having a coded wire tag (CWT), recognized by the absence of an adipose fin, were also sampled. Fish selected for feeding analysis were measured (fork length, mm) and their stomachs were removed and fixed in a 4% formaldehyde solution. In the laboratory, stomachs were transferred to 70% ethyl alcohol. Approximately 600 stomachs were collected; however, not all the stomachs could be analyzed because of time and funding constraints. All CWT salmon were examined first and a random subsample of the remaining fish was selected to provide at least 50 stomachs from each salmon species from each cruise, except Cruise 2 where all stomachs collected were examined because so few fish were caught. Twenty-one percent of the fish analyzed were CWT fish.

Stomach contents were identified to the lowest possible taxa with the aid of a 10X binocular microscope. Food items were counted, blotted, air dried for 10 min, and weighted to the nearest 0.1 mg.

Stomach content data were presented graphically using a method similar to that of Pinkas, Oliphant, and Iverson (1971), where percent number and percent weight of prey items are represented on the vertical axis and percent frequency of occurrence of prey items on the horizontal axis. To evaluate the importance of each prey item we calculated an Index of Relative Importance (IRI) (Pinkas et al. 1971):

$$IRI = F\ (N+W)$$

where

IRI = Index of Relative Importance,
F = percent frequency of occurence of a prey item for a fish species,
N = percent number of a prey for a fish species, and
W = percent weight of a prey item for a fish species.

The relative importance of a particular prey item can be more easily identified by expressing IRI values as percents. Percent IRI was calculated using the formula

$$\%\ IRI_i = \frac{IRI_i}{IRI_t} \times 100$$

where

$\%\ IRI_i$ = Percent Index of Relative Importance for prey item i,
$IRI_i$ = Index of Relative Importance for prey item i, and
$IRI_t$ = total of all Indexes of Relative Importance values for prey items of predator.

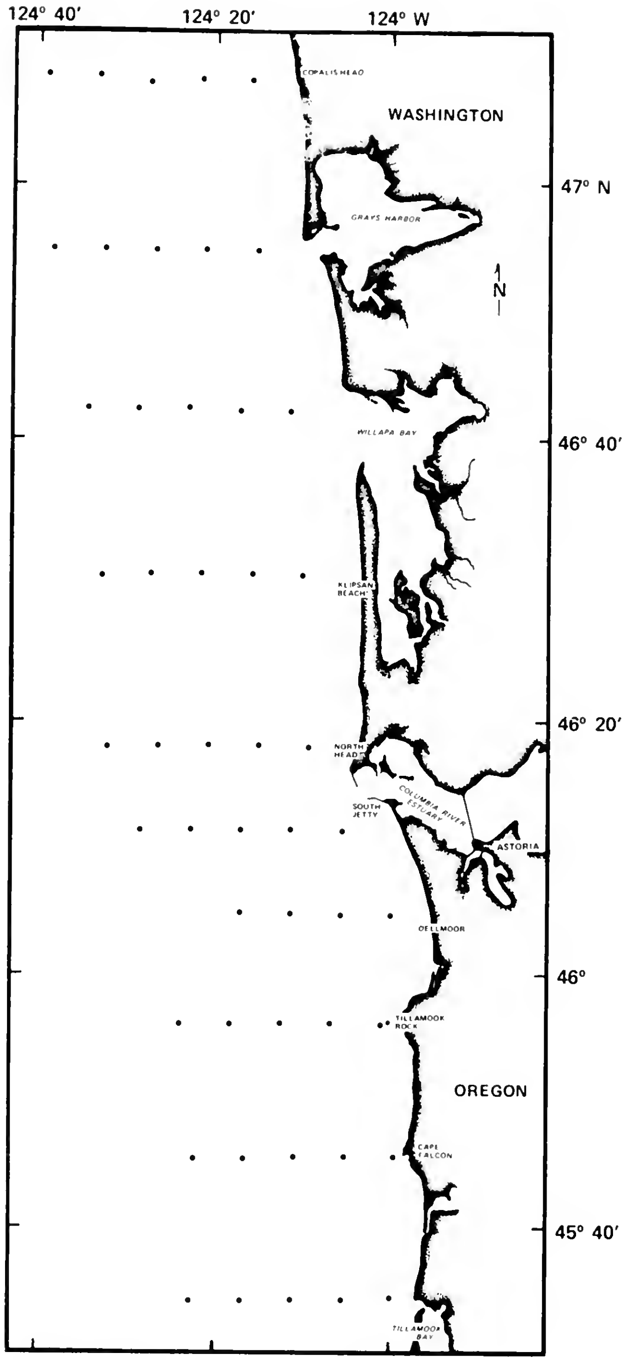


FIGURE 1. Transects and stations sampled during offshore purse seining for juvenile salmonids, May–September 1980.

Diet overlap values were calculated between the two species for each cruise to determine the potential for competition.

$$C = 2 \sum_{i=1}^{s} X_i Y_i \; / \sum_{i=1}^{s} X^2 + \sum_{i=1}^{s} Y^2$$

where

$C$ = overlap coefficient,

$s$ = food categories (lowest possible taxa),

$X_i$ = % weight contributed by food item i for fish species X (chinook salmon), and

$Y_i$ = % weight contributed by same food item i for fish species Y (coho salmon).

C ranges from 0 (no diet overlap) to 1 (complete overlap). Values $\geq 0.6$ are believed to indicate significant overlap (Zaret and Rand 1971).

An index of fullness was used to identify possible differences in feeding intensity. Fullness was evaluated by subjectively rating stomachs 1 to 7, with 1 being empty and 7 distended (Terry 1976).

## RESULTS

### Food

The food of juvenile chinook salmon sampled during the three cruises comprised six major prey groups (Figure 2). For chinook salmon captured during Cruise 1, fishes were the most important prey with crab larvae secondary. In Cruise 2, fishes were again the most important prey, although crab larvae were more important than in Cruise 1. During Cruise 3, hyperiid amphipods replaced fishes as chinook salmon primary prey. For coho salmon captured during Cruise 1, fishes were the primary prey with crab larvae, calanoid copepods, the gammarid amphipod *Atylus tridens,* and other invertebrates being secondary (Figure 2). In Cruise 2, fishes were still primary prey for juvenile coho salmon, but the euphausiid *Thysanoessa spinifera* was also important. In Cruise 3, hyperiid amphipods were primary prey for coho salmon, with the pelagic gastropod *Limacina* sp. secondary.

Besides differences in the IRI values of major prey groups (fish, crab larvae, etc.) between cruises, there were also changes in the species composition within prey groups for both species of salmon (Figures 3 and 4). For example, in Cruise 1, sand lance, *Ammodytes hexapterus;* rockfish, *Sebastes* spp., unidentified Osmeridae, and digested fish constituted most of the consumed fish; but in Cruise 2, *Sebastes* spp. alone constituted most of the consumed fish. In Cruise 3, northern anchovy, *Engraulis mordax,* and Pacific herring, *Clupea harengus pallasi,* were the fish primarily consumed. The species composition of crab larvae consumed also changed between surveys. In Cruise 1, chinook and coho salmon fed on Dungeness crab, *Cancer magister* (megalops); hermit crab, *Pagurus* spp. (megalops); and porcelain crab, Porcellanidae (megalops); whereas, in Cruise 2, crab larvae were primarily Oregon cancer crab, *Cancer oregonensis* (megalops).

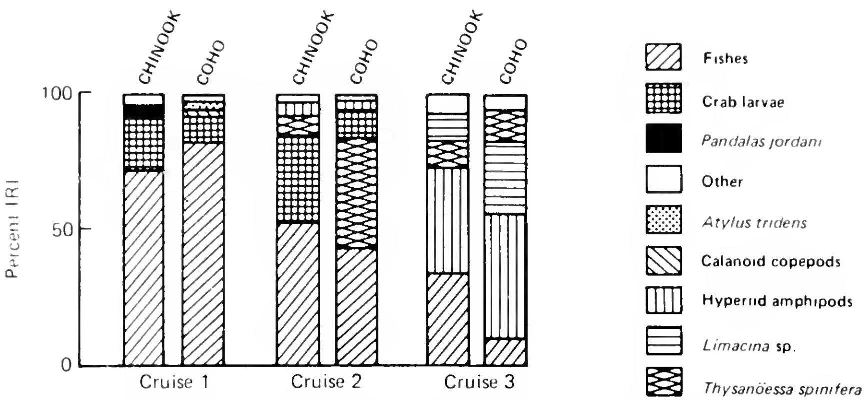


FIGURE 2. The food of juvenile chinook salmon, *Oncorhynchus tshawytscha,* and juvenile coho salmon, *O. kisutch,* captured by purse seine off northern Oregon and southern Washington during three cruises in 1980. Food is represented by Percent Index of Relative Importance (%IRI).

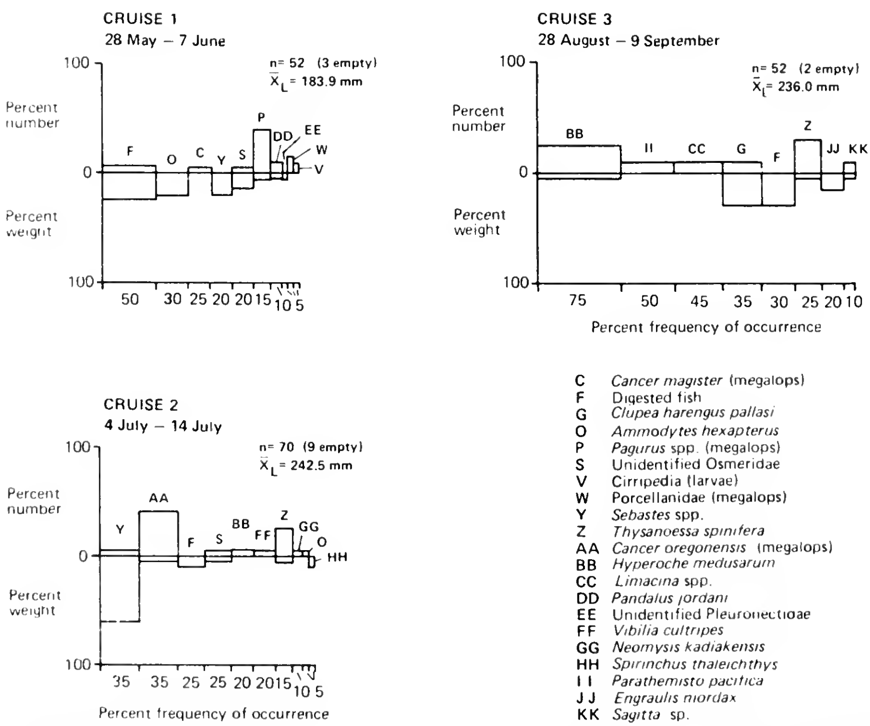


FIGURE 3. Food of juvenile chinook salmon, *Oncorhynchus tshawytscha,* captured by purse seine off northern Oregon and southern Washington during three cruises in 1980. Food is represented by numeric and gravimetric composition and by frequency of occurrence (n = sample size, $\bar{X}$ = mean fork length). Prey items less than 3% are omitted.

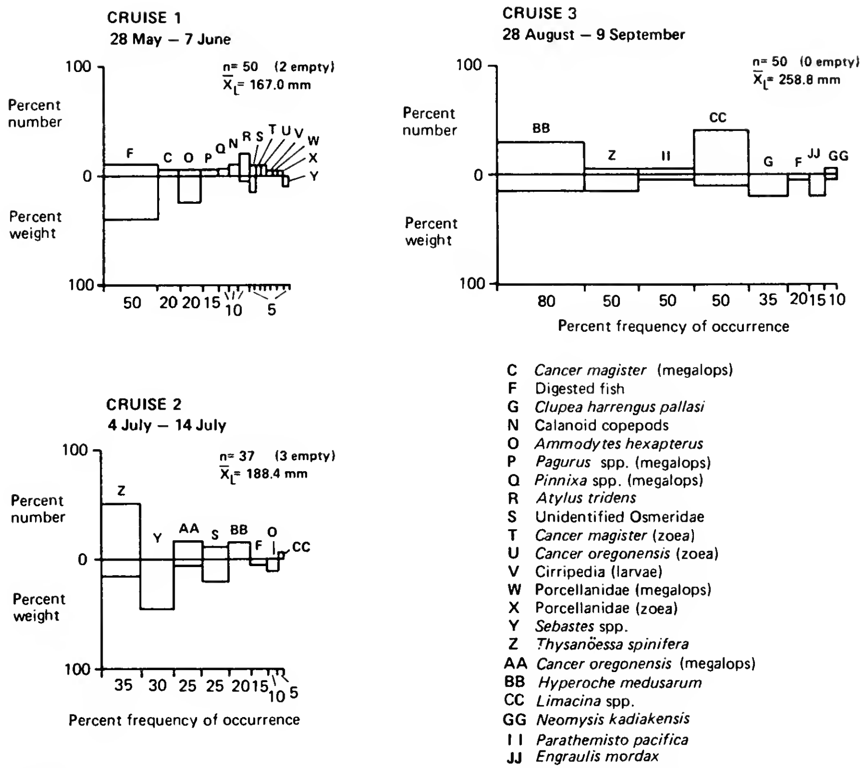


FIGURE 4. Food of juvenile coho salmon, *Oncorhynchus kisutch,* captured by purse seine off northern Oregon and southern Washington during three cruises in 1980. Food is represented by percent numeric and gravimetric composition and by frequency of occurrence (n = sample size, $\overline{X}$ = mean fork length). Prey items less than 3% are omitted.

## Diet Overlap

Diet overlap for the two salmon species was highest in Cruise 1 (C = 0.91) and lowest for Cruise 3 (C = 0.71); Cruise 2 diet overlap value was 0.90. This indicated significant diet overlap for all three cruises. During Cruises 1 and 2, chinook and coho salmon utilized similar fish species for primary prey, whereas during Cruise 3, chinook salmon consumed proportionally more fish than did coho salmon, which ate more *Limacina* sp. (Figure 2).

## Fullness

The intensity of feeding in juvenile chinook and coho salmon changed between cruises (Table 1). The lowest percentage of empty stomachs for both salmon species occurred during Cruise 3; the highest occurred in Cruise 2. The largest percentage of stomachs that were half full or better (percent index of fullness values of $\geq 4$) occurred in Cruise 3 for both chinook and coho salmon. The lowest percentage of stomachs that were half full or better occurred in Cruise 2 for chinook salmon and Cruise 1 for coho salmon.

**TABLE 1. Fullness of Juvenile Chinook, *Oncorhynchus tshawytscha*, and Coho, *O. kisutch*, Salmon Captured by Purse Seine During Three Cruises Off the Coasts of Northern Oregon and Southern Washington in Spring and Summer 1980. Fish Taken Were Divided into Categories of Fullness Ranging from 1 (Stomach Empty) to 7 (Stomach Fully Distended).**

| *Species* / *Cruise no. and date* | *Index of fullness values* | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | *1* (%) | *2* (%) | *3* (%) | *4* (%) | *5* (%) | *6* (%) | *7* (%) | *≥ 4* (%) |
| Chinook salmon | | | | | | | | |
| 1 (28 May–7 June) | 5.8 | 13.5 | 5.8 | 19.2 | 25.0 | 21.2 | 13.5 | 78.9 |
| 2 (4–15 July) | 12.2 | 5.4 | 13.5 | 16.2 | 8.1 | 14.9 | 29.7 | 68.9 |
| 3 (28 August–9 September | 3.8 | 3.9 | 5.8 | 11.5 | 11.5 | 19.2 | 44.2 | 91.7 |
| Coho salmon | | | | | | | | |
| 1 (28 May–7 June) | 3.8 | 21.2 | 17.3 | 21.2 | 13.5 | 9.6 | 13.5 | 57.8 |
| 2 (4–15 July) | 7.9 | 7.8 | 2.6 | 7.9 | 5.3 | 28.9 | 39.5 | 81.5 |
| 3 (28 August–9 September) | 0.0 | 6.0 | 2.0 | 18.0 | 12.0 | 24.0 | 38.0 | 92.0 |

## DISCUSSION

Our data indicate that the food of juvenile chinook and coho salmon changes from spring to late summer off the northern Oregon and southern Washington coasts. This change is probably directly related to changes in prey availability and abundance. The importance of juvenile nonsalmonid fishes to juvenile chinook and coho salmon diets in the spring correlates closely with abundance of coastal fish larvae populations off Yaquina Bay, Oregon, from February through July (Richardson and Pearcy 1977). The importance of hyperiid amphipods in juvenile chinook and coho salmon diets in late summer is probably related to their relative abundance at this time. Lorz and Pearcy (1975) found that the hyperiid amphipod species commonly consumed in this study were most abundant in plankton off Newport, Oregon, in late summer and fall. There is evidence that many hyperiid amphipods species have parasitoid relationships to jellyfish and other gelatinous plankton (Laval 1980). Therefore, jellyfish population dynamics may be an important component of juvenile salmonid feeding at certain times.

Previous studies of juvenile chinook and coho salmon marine feeding indicate simliar foods. Peterson et al. (1983) found fishes and invertebrates to be important prey in juvenile chinook and coho salmon collected off Oregon and southern Washington in June 1979, with euphausiids, amphipods, and crab larvae numerically important and fishes gravimetrically important. Their data most closely resemble our data from Cruise 2. Healey (1980) observed that fish (mainly Pacific herring) were an important prey of juvenile chinook and coho salmon in the Strait of Georgia, British Columbia. Our data indicate that herring were important only in late summer. The difference in herring consumption is probably a result of availability. Our observations, as did those of Healey (1980) and Peterson et al. (1983), showed that juvenile salmon fed on different prey in different geographic areas. For example, in Cruise 3, chinook and coho salmon captured north of the Columbia River consumed many anchovies; whereas, south of the Columbia River herring were an important prey and anchovies were rarely found in the diet. These diet differences may be due to patchy distributions of prey and to relative prey abundances. There also appeared to be a possible seasonal component to prey patchiness and/or relative abundance. For example, during Cruise 3, four prey items occurred in at least 50% of the coho salmon stomachs, but in Cruise 2, no item had a frequency of occurrence over 50%; in Cruise 1 only one item had a frequency of occurrence over 50%.

It is difficult to assess the time of poorest feeding, although data from Cruise 2 indicate a possible reduction in feeding. The largest percentage of empty stomachs for both species occurred during Cruise 2, and this was also when chinook salmon had the fewest stomachs that were at least half full. Also, in Cruise 2 the fewest juvenile salmonids were captured (Miller et al. 1983). High ocean temperature (surface water temperatures for Cruise 2 averaged 15.2°C) may have caused juvenile salmon to move into deeper water where they could not be captured by purse seine. Godfrey (1968) found poor juvenile salmonid captures at high ocean temperatures off British Columbia. Salmonids may also have migrated to better feeding areas; Healey (1980) found a direct correlation between coho salmon abundance and amounts of food in their stomachs.

Juvenile chinook and coho salmon showed a large degree of diet overlap for all three cruises. High diet overlap values may indicate abundant food supply and not competition (Zaret and Rand 1971). The high diet overlap along with the low percentage of empty stomachs and relatively high percentage of stomachs that were greater than half full are evidence that no food shortages occurred for juvenile chinook and coho salmon off the northern Oregon and southern Washington coasts in 1980. Growth rates derived from fishes caught in this study also do not suggest food limitations (Miller et al. 1983).

An important component of the feeding habits of many fish species is the time of day. Fish used in this study were collected at various times during daylight hours, yet many salmonid species have diel feeding behavior (Godin 1981). Prey species also have diel behavior patterns (Alton and Blackburn 1972, Youngbluth 1976) which may affect salmon feeding rates. Peterson et al. (1983) found no significant differences in the diets of salmon collected at different times of the day; however, their information was collected during 1 month in 1979, and they combined data from many different sampling stations.

To accurately assess potential limitations of salmonid prey in coastal waters will require a more rigorous study. Salmonid digestion rates, migration patterns, and feeding behavior, along with prey availability, prey distributions, predation rates, and prey population dynamics would be required. Of special need would be a sustained series of offshore collections of juvenile salmon, their prey, and other biological and physical data during both weak and strong upwelling years. These data could then be compared to assess the relationship of upwelling to salmonid feeding.

## ACKNOWLEDGMENTS

We thank G. McCabe, J. Monan, and D. Damkaer for their review and advice on the paper. Particular thanks go to the crew of the FLAMINGO, who performed the ocean purse seining.

## LITERATURE CITED

Allen, G. H., and W. Aron. 1958. Food of salmonid fishes of the western north Pacific Ocean. U.S. Fish Wildl. Serv., Special Sci. Rept. 237:1–11.

Alton, M. S., and C. J. Blackburn. 1972. Diel changes in the vertical distribution of the euphausiids, *Thysanoessa spinifera* Holmes, and *Euphausia pacifica* Hansen, in coastal waters of Washington. Calif. Fish Game, 58(3):179–190.

Andrievskaya, L. D. 1957. The food of Pacific salmon in the northwestern Pacific Ocean (In Russian). Materially po Biologii Morsxovo Perioda Zhizni Dalnevostochnykh Lososei. p. 69–75. Moscow. (Fish Res. Board Can. Transl. Ser. 182).

Godfrey, H. 1968. Some observations of juvenile marine chum, chinook and coho salmon taken in waters adjacent to Georgia Strait in 1965. Fish. Res. Board Can. MS Rept. 955:1–19.

Godin, J. G. J. 1981. Daily patterns of feeding behavior, daily rations, and diets of juvenile pink salmon *(Oncorhynchus gorbuscha)* in two marine bays of British Columbia. Can. J. Fish. Aquat. Sci., 38:10–15.

Gunsolus, R. T. 1978. The status of Oregon coho and recommendations for managing the production, harvest, and escapement of wild and hatchery reared stocks. Oreg. Dep. Fish Wildl., Columbia Region, Portland, Oreg., 59 p.

Healey, M. C. 1978. The distribution, abundance, and feeding habits of juvenile Pacific salmon in Georgia Strait, British Columbia. Fish. Mar. Serv. Tech. Rep. 788:1–49.

________. 1980. The ecology of juvenile salmon in Georgia Strait, British Columbia. Pages 203–229 *in,* W. J. McNeil and D. C. Himsworth, eds., Salmonid ecosystems of the North Pacific, Oreg. St. Univ. Press, Corvallis.

Ito, J. 1964. Food and feeding habits of Pacific salmon (Genus *Oncorhynchus*) in their ocean life. Bull. Hokkaido Reg. Fish. Res. Lab. 29:85–97. (Fish. Res. Board Can. Transl. Ser. 1309).

Laval, P. 1980. Hyperiid amphipods as crustacean parasitoids associated with gelatinous zooplankton. Oceanogr. Mar. Bio. Ann. Rev., 18:11–56.

LeBrasseur, R. J. 1966. Stomach contents of salmon and steelhead trout in the northeastern Pacific Ocean. Can., Fish. Res. Bd., J., 23:85–100.

Lorz (Van Arsdale), H., and W. G. Pearcy. 1975. Distribution of hyperiid amphipods off the Oregon coast. Can., Fish. Res. Bd., J., 32:1442–1447.

Merkel, T. J. 1957. Food habits of king salmon, *Oncorhynchus tshawytscha* (Walbaum), in the vicinity of San Francisco, California. Calif. Fish. Game, 43(4):249–270.

Miller, D. R., J. G. Williams, and C. W. Sims. 1983. Distribution, abundance and growth of juvenile salmonids off the coast of Oregon and Washington, summer 1980. Fish. Res. (Amsterdam) 2:1–17.

Oregon Department of Fish and Wildlife. 1982. Comprehensive plan for production and management of Oregon's anadromous salmon and trout. Part 2. Coho salmon plan. Oreg. Dep. Fish Wildl., Fish Div., Anadromous Fish. Sect., Portland, Oreg.

Peterson, W. T., R. D. Brodeur, and W. A. Pearcy. 1983. Feeding habits of juvenile salmonids in the Oregon coastal zone in June 1979. Fish Bull., U.S. 80(4): 841–851.

Pinkas, L., M. S. Oliphant, and I. L. K. Iverson. 1971. Food habits of albacore, bluefin tuna, and bonita in California waters. Calif. Dept. Fish Game, Fish. Bull. (152):1–105.

Reimers, P. E. 1964. A modified method of analyzing stomach contents with notes on the food habits of coho salmon in the coastal waters of Oregon and southern Washington. Fish. Comm. Oreg. Res. Briefs 3:32–40.

Richardson, S. L., and W. G. Pearcy. 1977. Coastal and oceanic fish larvae in an area of upwelling off Yaquina Bay, Oregon. Fish. Bull., U.S. 75:125–145.

Silliman, R. P. 1941. Fluctuations in the diet of chinook and silver salmon (*Oncorhynchus tshawytscha* and *O. kisutch*) of Washington as related to the troll catch of salmon. Copeia, 2:80–87.

Terry, C. 1976. Stomach analysis methodology: still lots of questions. Pages 87–92. *in,* C. A. Simenstad and S. J. Lipovsky, (eds.), Fish Food Habits Studies, 1st Pacific Northwest Technical Workshop. Univ. Wash. Press, Seattle.

Youngbluth, M. 1976. Vertical distribution and diel migration of euphausiids in the central region of the California current. Fish. Bull., U.S. 74:925–936.

Zaret, T. M., and A. S. Rand. 1971. Competition in tropical stream fishes: support for the competitive exclusion principle. Ecology, 52:336–342.

*Calif. Fish and Game* 72(1): 47–61 1986

# LINE-TRANSECT CENSUSES OF FALLOW AND BLACK-TAILED DEER ON THE POINT REYES PENINSULA [1]

PETER J. P. GOGAN
Department of Forestry and Resource Management
University of California
Berkeley, California 94720

STEVEN C. THOMPSON [2]
WILLIAM PIERCE [3]
Point Reyes National Seashore
Point Reyes, California 94956
AND
REGINALD H. BARRETT
Department of Forestry and Resource Management
University of California
Berkeley, California 94720

**Fallow and black-tailed deer are sympatric on Point Reyes Peninsula. Management objectives of the National Park Service require accurate monitoring of trends in numbers and composition of both species. Line transect sampling was coupled with refined estimation techniques to calculate density of fallow deer in the coastal prairie habitat type and for black-tailed deer in both coastal prairie and coastal scrub habitat types and in a mosaic of both types. Density estimates are higher (fallow—20.3/km $^2$: black-tailed—9.4–20.7/km $^2$) than recorded by other census techniques. Neither species was observed frequently enough in the forest type for analysis. The sampling effort required to generate a population estimate with a coefficient of variation of 20% or less is 43 km for both species in coastal prairie, and 83 km and 150 km for fallow and black-tailed deer, respectively, in coastal scrub, and 42 km for black-tailed deer in the mosaic.**

## INTRODUCTION

The introduction of pastoralism to the Point Reyes Peninsula in the 1830's initiated a trend which has continued to this day. The species composition and abundance of large herbivores was transformed rapidly from one of tule elk, *Cervus elaphus,* and black-tailed deer, *Odocoileus hemionus,* to include cattle, *Bos taurus,* horses, *Equus caballus,* pigs, *Sus scrofa,* goats, *Capra* spp., and sheep, *Ovis aries* (Toogood 1980). This stabilized in the latter part of the 19th century with extirpation of the tule elk (Mason 1970), elimination of pigs and range horses, and establishment of productive dairies (Toogood 1980). The indigenous human population died off or was resettled (Toogood 1980). Land was cleared of brush to increase pastorage and for silage production, and a wide range of exotic plants was introduced (Heady et al. 1977). Grizzly bear, *Ursus arctos,* were extirpated sometime after the 1860's (Van Atta 1946), and mountain lion, *Felis concolor,* were possibly absent from the early 1930's through the early 1970's. Numbers of golden eagles, *Aquila chrysaetos,* and bald eagles, *Haliaeetus leucocephalus,* were greatly reduced. Coyote, *Canis latrans,* were eliminated in the 1940's (Clark 1982), but have been sighted sporadically since 1982. A population of red foxes, *Vulpes vulpes,* has become established in the

[1] Accepted for publication May 1985. This is Welder Wildlife Foundation Contribution Number 155.
[2] Mr. Thompson's present address: Division of Wildlife and Fisheries Biology, University of California, Davis, California 95616.
[3] Mr. Pierce's present address: Shenandoah National Park, Luray, Virginia 22835.

vicinity of the Point Reyes Headlands as the result of an unauthorized introduction. In the 1940's, populations of axis deer, *Axis axis,* and fallow deer, *Dama dama,* were established (Wehausen and Elliott 1982). Tule elk were reintroduced in 1978. Sympatric use of rangelands by wild and domestic ungulates has led to the establishment of livestock diseases in the wild ungulate populations (Rafiquzzaman 1977, Riemann et al. 1977, Jessup et al. 1981).

Little is known of the impact of these activities on numbers and distribution of the resident population of black-tailed deer. Generally, California's deer populations were reduced markedly between 1849 and 1900 (Longhurst, Leopold, and Dasmann 1952). However, numbers of native deer in California's north-coastal counties have been declining since 1969 (Longhurst et al. 1976). The magnitude of any shift in numbers of black-tailed deer on the Point Reyes Peninsula is unknown.

With the establishment of Point Reyes National Seashore in the 1960's, pastoralism was halted over much of the peninsula. However, the Seashore's natural resource management plan (National Park Service 1976) delineates a pastoral zone in which traditional livestock production is to be permitted to continue. The plan also calls for limiting numbers of exotic deer to no more than 350 of each species while maintaining a healthy population of black-tailed deer. A direct reduction program undertaken by Seashore staff in the pastoral zone removed several hundred exotic deer between 1976 and 1981. Axis deer remain confined to the pastoral zone and total approximately 250 (Thompson, unpubl. data). Fallow deer were estimated to number 523 in 1977 (Wehausen and Elliott 1982). Frequent observations of fallow deer suggest that their numbers have continued to increase. The population is widespread over much of the peninsula. Consequently, the exotic deer reduction program was extended into the southern zone in 1980.

The management mandate requires manipulation of exotic deer populations coupled with an ability to monitor trends in numbers and distribution of all deer species. The Seashore's deer populations have been censused sporadically by aerial total counts (Wehausen and Elliott 1982) and sample area counts (Dasmann and Taber 1955, Elliott, unpubl. data, Nystrome and Stone, unpubl. data, Thompson, unpubl. data), and by drive counts (Elliott, Wehausen, and Barrett, unpubl. data). However, each method has serious disadvantages. The tendency to underestimate population size by total counts is well documented (Norton-Griffiths 1978), as is the potential of observers in aerial counts to underestimate group size or overlook groups (Graham and Bell 1969, Pennycuick and Western 1972, Caughley 1974). Sample area counts require a novice observer to spend at least 4 months becoming familiar with the area's topography and the distribution and habits of the target species (Elliott, unpubl. data).

As an alternative, we elected to explore the feasibility of making annual population estimates of deer numbers on the Point Reyes Peninsula using line-transect censuses. Specific objectives of the southern zone censuses were to: (i) estimate fallow deer densities, age and sex composition, and color phase, (ii) evaluate changes in the above relative to the reduction program, (iii) estimate black-tailed deer densities, age and sex composition, and (iv) detect any dispersal of axis deer into the area.

The objective of the pastoral zone census was to estimate black-tailed deer densities, age, and sex composition.

Results from censuses in both areas were used to calculate the sampling intensity required to obtain a population estimate with a coefficient of variation of 20% or less.

## STUDY AREA

The Point Reyes Peninsula lies about 32 km northwest of San Francisco, California, immediately west of the San Andreas fault zone (Figure 1). Inverness Ridge forms a backbone along the peninsula, rising to a height of 448 m at Mount Wittenburg and dropping abruptly into the sea at Tomales Point. A broad, flat arm protrudes into the Pacific Ocean.

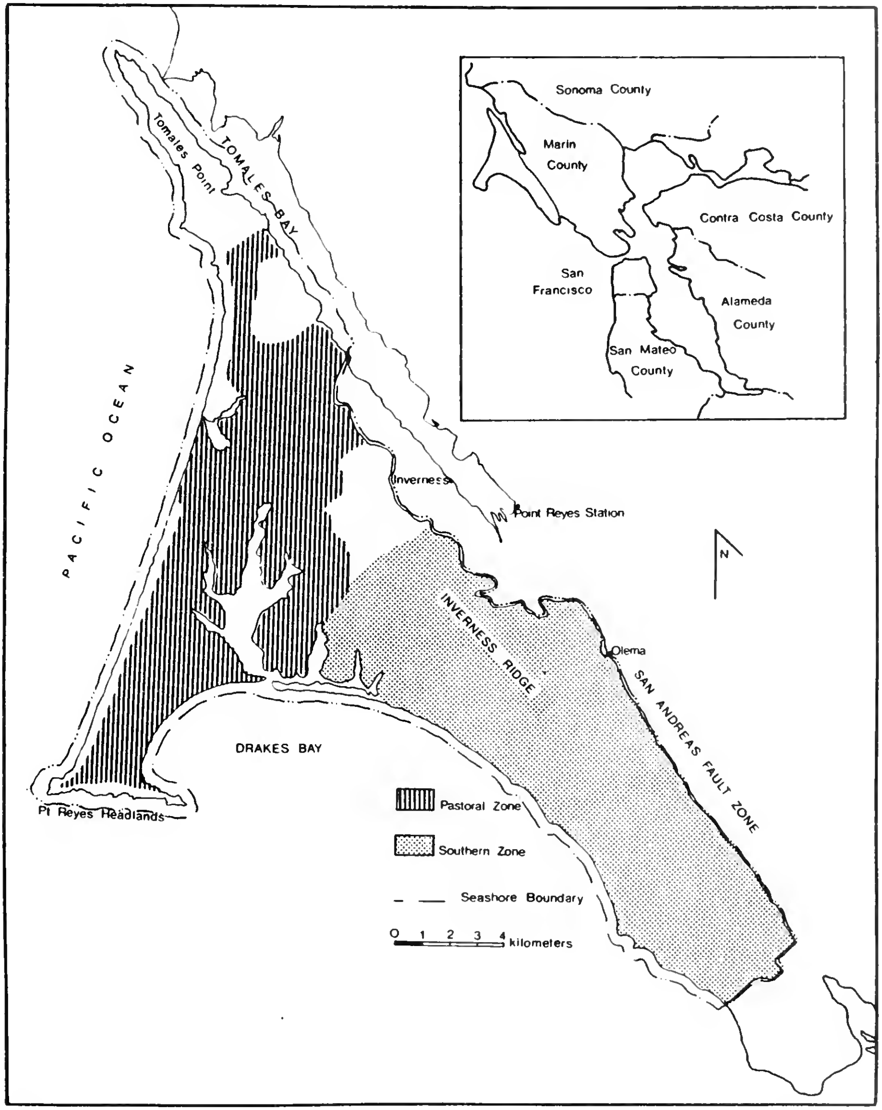


FIGURE 1. Location of the pastoral and southern zones in Point Reyes National Seashore.

The study area embraces two units of Point Reyes National Seashore: a southern zone of 11,150 ha, chiefly designated wilderness, and a pastoral zone of 8,100 ha. Ranching activities were halted in all but a few peripheral portions of the southern zone and most domestic stock were removed between 1962 and 1972. A network of former ranch roads are used as hiking trails by large numbers of visitors. Traditional livestock practices continue in the pastoral zone, including both beef and dairy ranches. Annual stocking rates average 0.33 animal units/ha (Elliott 1982).

The vegetation has been mapped in detail (Lauer 1972) and may be categorized into three general types (Figure 2): (i) forest, (ii) coastal scrub, and (iii) coastal prairie (Kuchler 1977). The forest consists of extensive stands of Douglas-fir, *Pseudotsuga menziesii,* and California laurel, *Umbellularia californica,* with riparian woodlands of alders, *Alnus* spp., and willows, *Salix* spp. Stands of Bishop pine, *Pinus muricata,* occur along the eastern boundary. Coastal shrub dominated by coyote bush, *Baccharis pilularis,* is common on north-facing slopes. Species composition is more diverse and includes sagebrush, *Artemisia californica,* and poison oak, *Rhus diversiloba* (Grams et al. 1977). Coastal prairie is dominated by California brome, *Bromus carinatus,* tufted hairgrass, *Deschampsia caespitosa* and sheep sorrel, *Rumex acetosella,* although fallow fields support an abundance of annuals (Elliott and Wehausen 1974). In the southern zone, forest is the most extensive habitat type, especially abundant in the southeastern portion of the area (5,018 ha or 45% of the total area) (Figure 2). Coastal scrub lies as a belt intermediate between forest and prairie (3,456 ha; 31%). Prairie is prevalent in the northwest section and occurs elsewhere as a narrow band along the coastline and eastern boundary (2,676 ha; 24%). In the pastoral zone many scrub fields have been cleared to favor pastorage production. Both prairie and scrub have been tilled and planted to a combination of oats, *Avena sativa,* and vetch, *Vicia* spp., for silage production (Elliott 1982).

## METHODS

Transects were run by Seashore personnel; the resulting data were analyzed with program TRANSECT (Burnham, Anderson, and Laake 1980) on an IBM 4341A computer at the University of California, Berkeley. Three censuses were made of fallow and black-tailed deer in the southern zone in 1980, 1981, and 1982. Black-tailed deer were censused in the pastoral zone once in 1980. Sampling methods differed only slightly between the southern and pastoral zones. Transect lines were located differently in the two areas, and fallow deer were recorded only in the southern zone. Identical procedures were used to estimate density and calculate required future sampling efforts.

### Location of Transects

In the southern zone, the distribution of the three habitat types was plotted on USGS 7.5-minute quadrangle maps and their area determined by applying a dot-grid transparency (Avery 1975). The trail system was broken into numbered 1-km sections. Twenty numbered trail sections were selected at random within each habitat type. The ends of selected sections were located in the field and marked with 1-m pieces of rebar. Transects were walked by two-person teams from 16 to 20 September 1980, 21 to 24 September 1981, and 25–28 November

1982. Team movements were coordinated to ensure that deer along transects were not disturbed prior to being censused. Counts were made within 3 hours of sunrise.

In the pastoral zone, a universal transverse mercator (UTM) grid 500 m on each side was applied to a 7.5-minute USGS map. Points along the main road system intersected by the grid were numbered and 30 points were selected at random. At each point, a direction of true east or true west was randomly selected. A line 1-km in length was laid out in the selected direction. We determined whether the transect traversed any obstacles (ravines, scrub fields) judged to be impassable on foot by use of a combination of aerial photographs, the USGS map, and on-site inspection. If so, the alternate direction was evaluated under the same criteria. If both directions were considered impassable, the point was discarded and another selected at random. This process was repeated until 30 1-km transects either east or west had been selected. The points were marked at the roadside with a 1.3-m length of rebar. Transects were traversed on foot by two-person teams within 3 hours of sunrise between 8 and 12 December 1980. Each team maintained its direction by compass and determined the distance traveled by pedometer and reference to aerial photographs.

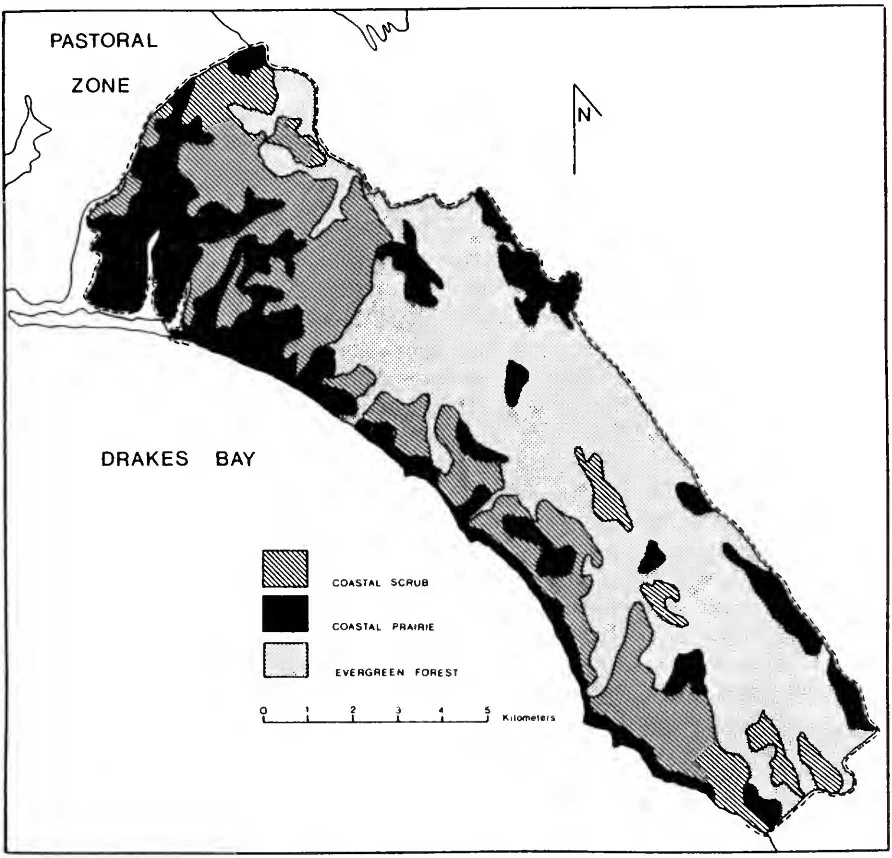


FIGURE 2. Distribution of vegetative types in the southern zone of Point Reyes National Seashore.

## Data Recorded

Upon sighting deer, observers recorded species, group size, sighting angle measured with a compass, and sighting distance to the center of each group, measured with an optical range finder. Group composition was recorded as adult (1 + years), male or female and unsexed fawns for both deer species. Color phases of fallow deer were recorded as: (i) white, (ii) black, and (iii) other. The latter category consisted of both "common" and "menil" animals (Chapman and Chapman 1982), not readily distinguished in the field.

## Data Analyses

Each group is treated as a single sighting. Estimates of density of deer groups were calculated from appropriate data sets with the Fourier series, exponential polynomial, and exponential power series estimators of program TRANSECT (Burnham et al. 1980). Each estimator uses a different model to describe the probability density function (PDF). The Fourier series is recommended as a general estimator as it is nonparametric and both, "model robust, pooling robust, and has the shape criterion and high estimator efficiency" (Burnham et al. 1980:133). However, the Fourier series seriously underestimates density if animals move away from the observer prior to detection. The extent to which deer move away from the transect line prior to detection cannot be measured. However, a frequency distribution of observation distances with fewer observations in the grouping interval closer to the observer is indicative of deer movement away from the observer prior to detection. The exponential power series and exponential polynomial estimators are more robust than the Fourier series to this possibility. A chi-squared test of the distribution of observations relative to each model's PDF provides the criteria to select the most appropriate model. A sample size of at least 40 observations is recommended (Burnham et al. 1980). Only our sample for the pastoral zone transects exceeds this minimum. However, we analyzed all samples of 30 or more observations. Samples of between 30 and 40 observations may be expected to generate numerically reliable estimates of population density but with increased variances (Burnham, pers. commun.).

All observations of deer in the southern zone over 300 m from the line of travel were omitted. The remainder were grouped into perpendicular distance classes of 0–30, 31–60, 61–90, 91–120, 121–180, 181–240, and 241–300 m prior to analysis by program TRANSECT (Burnham et al. 1980). Selection of a width of 300 m complies with the recommendation of Burnham et al. (1980) of removing the effect of outlier observations while maintaining a transect width considerably larger than the mean perpendicular sighting distance. Observations of deer groups in the pastoral zone were truncated at a perpendicular distance of 250 m and grouped into 30-m intervals to 120 m, 121 to 180 m, and 181 to 250 m for analysis by program TRANSECT (Burnham et al. 1980). A width of 250 m ensured no overlap between adjacent transect lines. Grouping helps remove the effect of rounding errors and observer variation in measuring sighting distance and angle (Burnham, Anderson, and Laake 1981).

The density of individuals was calculated by combining an estimate of group density and its standard error with the mean and standard error of group size (Burnham et al. 1981:475). The standard error is used to calculate a 90% confidence interval of the estimate. Numbers were obtained by multiplying the density estimate by the area calculated for each habitat type in the southern zone or by the area of the pastoral zone.

The length of transect line required for a desired percent coefficient of variation based upon the variability of a pilot survey is calculated by the formula:

$$L = \frac{b}{(CV_2(D))^2} \qquad \frac{L_1}{n_1}$$

(Burnham et al. 1980:36) where L is the length of transect line required to obtain a desired coefficient of variation ($CV_2(D)$) and $n_1$ is the number of animal groups sighted in a pilot census of length $L_1$. The factor b is calculated from the formula:

$$b = n_1 \ (CV_1(D))^2$$

where $n_1$ is as above and ($CV_1(D)$) is the coefficient of variation of the pilot survey. A value of b = 3 is recommended as slightly overestimating the sample required (Burnham et al. 1980:35) and is used in our calculations.

Estimates were made of the length of transect line required for a coefficient of variation of 20 percent using the 1980 counts for the southern zone and the single count for the pastoral zone as pilot surveys.

## RESULTS AND DISCUSSION

### Population Composition

Southern Zone

Fallow and black-tailed deer were sighted in all habitat types (Table 1). No axis deer were seen in the southern zone in any year. Thirty or more groups of fallow deer were sighted only once in any habitat type. Thirty or more groups of black-tailed deer were sighted in grassland in all years and in scrub in 1981. The paucity of observations of both species in the forest type should not be interpreted as indicative of low densities, as the number of animals sighted is a poor index to density (Burnham et al. 1981). Rather, it simply reflects a failure to sight adequate numbers for analysis at our sampling intensity.

The number of groups of fallow deer sighted declined continuously over the 3 years (Table 1). This is undoubtedly due in part to the removal of animals but likely is attributable also to a general shift in the distribution of fallow deer away from trails and out of the area in response to shooting pressure. Rangers observed a concurrent increase in the abundance of fallow deer in the pastoral lands to the north. Movement of fallow deer in response to shooting has been reported elsewhere (Chapman and Chapman 1982). Similarly, Houston (1982) noted that elk avoided areas adjacent to roads for a number of years following a reduction program. A Kruskall-Wallis test of differences in mean group sizes between habitat types for all years was highly significant ($X^2$, $P < .001$). Average group size was consistently largest in the prairie type. Schall (1982) reported similar findings in Alsace Province, France.

A contingency test shows the proportions of age and sex classes of fallow deer for all years (Table 2) are significantly different ($X^2$, $P < .01$). The ratio of males and fawns to female fallow deer was notably higher in 1980 and 1981 than in 1982. Partitioning the contingency table (Zar 1974) revealed a non-significant difference between 1980 and 1981 ($X^2$, $P < .10$). The difference between the first two and third years likely reflects a difference in the visibility of males in September 1980 and 1981 in contrast to November 1982, and a low proportion of fawns in 1982.

**TABLE 1. Number of Sightings, Group Size, and Perpendicular Sighting Distance (meters) for Fallow and Black-tailed Deer in 1980, 1981, and 1982, Along 60 One-Kilometer Transects Distributed Equally Among Three Habitat Types in the Southern Zone of Point Reyes National Seashore. Percent given in parentheses.**

| | Fallow deer | | | | | Black-tailed deer | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Group size | | Perpendicular sighting distance | | | Group size | | Perpendicular sighting distance | |
| *Year Habitat type* | *Sightings* | *Mean* | *S.E.* | *Mean* | *S.E.* | *Sightings* | *Mean* | *S.E.* | *Mean* | *S.E.* |
| 1980 | | | | | | | | | | |
| Coastal prairie | 39 (64) | 3.69 | 0.54 | 98 | 20.5 | 35 (66) | 2.03 | 0.20 | 110 | 25.8 |
| Coastal scrub | 18 (28) | 2.72 | 0.54 | 197 | 67.2 | 10 (18) | 1.30 | 0.15 | 100 | 43.3 |
| Forest | 4 (8) | 1.50 | 0.29 | 53 | 20.5 | 9 (16) | 1.55 | 0.24 | 10 | 53.4 |
| 1981 | | | | | | | | | | |
| Coastal prairie | 16 (38) | 3.19 | 0.76 | 181 | 55.5 | 37 (50) | 1.72 | 0.17 | 122 | 26.2 |
| Coastal scrub | 20 (45) | 1.30 | 0.11 | 138 | 43.4 | 30 (42) | 1.53 | 0.16 | 139 | 29.9 |
| Forest | 7 (17) | 1.57 | 0.62 | 56 | 35.5 | 6 (8) | 1.66 | 0.33 | 81 | 37.6 |
| 1982 | | | | | | | | | | |
| Coastal prairie | 13 (68) | 3.15 | 0.69 | 105 | 54.9 | 31 (70) | 2.06 | 0.20 | 76 | 12.2 |
| Coastal scrub | 6 (32) | 2.16 | 0.60 | 144 | 70.2 | 10 (23) | 2.20 | 0.42 | 116 | 39.8 |
| Forest | 0 (0) | — | — | — | — | 3 (7) | 1.33 | 0.43 | 26 | 1.87 |

**TABLE 2. Sex, Age, and Color Composition of Fallow Deer in the Southern Zone of Point Reyes National Seashore in 1980, 1981, and 1982. Percent given in parentheses.**

| *Year* | *Total deer* | *Sex and Age class* | *Total* | *Color Phase* *White* | *Black* | *Other* | *Males:* | *100 Females:* | *Fawns* | *Unknown* |
|---|---|---|---|---|---|---|---|---|---|---|
| 1980 .......................... | 199 | Adult male | 46 (33) | 24 (52) | 10 (22) | 12 (26) | 67 : | 100 : | 35 | 60 |
| | | Adult female | 69 (50) | 33 (48) | 9 (13) | 27 (39) | | | | |
| | | Fawn | 24 (17) | 7 (29) | 0 | 17 (71) | | | | |
| | | All classes | 130 | 64 (46) | 19 (14) | 56 (40) | | | | |
| 1981 .......................... | 89 | Adult male | 30 (37) | 19 (66) | 4 (14) | 6 (20) | 73 : | 100 : | 27 | 7 |
| | | Adult female | 41 (50) | 16 (39) | 15 (37) | 10 (24) | | | | |
| | | Fawn | 11 (13) | 0 | 4 (36) | 7 (64) | | | | |
| | | All classes | 82 | 35 (43) | 23 (28) | 24 (29) | | | | |
| 1982 .......................... | 58 | Adult male | 15 (26) | 8 (53) | 4 (27) | 3 (20) | 36 : | 100 : | 3 | 1 |
| | | Adult female | 41 (72) | 20 (49) | 9 (22) | 12 (29) | | | | |
| | | Fawn | 1 (2) | 0 | 0 | 1 (100) | | | | |
| | | All classes | 57 | 28 (49) | 13 (23) | 16 (28) | | | | |

The age ratios reported in this study are consistently lower than observed in the 1970's (Wehausen 1973, Wehausen and Elliott 1982).

The white color phase was predominant in the original introduction (Wehausen 1973) and remains prevalent in adults. Few fawns are classified as white because the white phase is a light tan color through the first year of life (Wehausen 1973). The possibility of adult color or group size influencing detectability of fallow deer measured by perpendicular sighting distance was investigated by subjecting the 1980 observations to a 3-way analysis of variance (Sokal and Rohlf 1969) on the effect of: (i) habitat type, (ii) group size classified as one or greater than one, and (iii) animal color classified as white or nonwhite. A significant ($P = 0.10$) difference in observability was found only between habitat types. Thus, the proportions of color phases may be considered representative.

No trend was evident in the number of black-tailed deer groups observed during the three counts (Table 1), indicating no tendency for this species to move away from trails in response to shooting. The higher number of observations in 1981 reflects an increase in sightings in scrub for one year. A Kruskall-Wallis test of differences in mean group sizes between habitat types was non-significant ($X^2$, $P < .14$). A contingency test shows differences in proportions of age and sex classes between years (Table 3) are highly significant ($X^2$, $P < .0005$). The ratio of males and fawns to female black-tailed deer was notably higher in 1980 and 1981 than in 1982. Partitioning the contingency (Zar 1974) revealed a non-significant difference between 1980 and 1981 ($X^2$, $P < .25$).

**TABLE 3. Sex and Age Composition of Black-tailed Deer in the Southern Zone of Point Reyes National Seashore in 1980, 1981, and 1982. Percent given in parentheses.**

| | Total | Sex and age class | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *Year* | *deer* | *Males* | *Females* | *Fawns* | *Unknowns* | *Males:* | *100 Females:* | *Fawns* |
| 1980 | 100 | 40 (40) | 42 (42) | 14 (14) | 4 (4) | 95: | 100 : | 33 |
| 1981 | 120 | 56 (47) | 46 (38) | 16 (13) | 2 (2) | 122: | 100 : | 35 |
| 1982 | 90 | 20 (22) | 61 (68) | 9 (10) | 0 | 33: | 100 : | 15 |

The above differences likely reflect differences in the timing of the 1980 and 1981 censuses, as opposed to 1982. The marked decline in the number of adult males: 100 females in 1982 may be attributable to differences in the behavior of males at the close of the rut in late November (Dasmann and Taber 1956). Adult males are likely over-represented in herd composition counts made during the rut from late September through November (Dasmann and Taber 1956, Taber and Dasmann 1958).

## Pastoral Zone

A total of 195 black-tailed deer in 54 groups was sighted along the 30 km of transect in the pastoral zone. Group size ranged from solitary individuals to 12. The ratio of males to females (Table 4) approximates ratios recorded in the southern zone in November 1982 (Table 3) and the pastoral zone in October 1971 (Elliott, Wehausen and Barrett, unpubl. data). The ratio of 32 fawns: 100 females is similar to our observations in the southern zone in November 1980 and 1981 (Table 3). A ratio of 64 fawns: 100 does was recorded in January and February 1981 over a smaller portion of the pastoral zone (Thompson, unpub. data). Composition counts made in the north coast range of California in mid-December are likely to be representative of the population (Dasmann and Taber 1956, Taber and Dasmann 1958).

**TABLE 4. Sex and Age Composition of Black-tailed Deer in the Pastoral Zone (n=195) of Point Reyes National Seashore in 1980. Percent given in parentheses.**

| *Sex and age class* | | | | | |
|---|---|---|---|---|---|
| *Males:* | *Females:* | *Fawns* | *Males:* | *100 Females:* | *Fawns* |
| 30 (15) | 125 (64) | 40 (21) | 24 : | 100 : | 32 |

## Density Estimates

### Southern Zone

Insufficient observations were made of fallow deer in either the coastal scrub or forest habitats in 1980 to calculate densities. Counts in 1981 and 1982 were made in areas likely being avoided by fallow deer and are not suitable for analysis. Thus, fallow deer density is calculated only for the coastal prairie habitat type in 1980. Observations of black-tailed deer in the coastal prairie type were judged to be adequate to generate annual estimates of density in each year together with an averaged and pooled estimate for all 3 years combined (Burnham et al. 1981). Observations in the coastal scrub type were sufficient to generate an estimate of density only in 1980.

The population estimate for fallow deer (Table 5) superficially approximated results of a minimum total count of 523 from a helicopter survey centered on the pastoral lands in 1977 (Elliott, unpubl. data, Wehausen and Elliott 1982). However, density estimates derived from previous counts ranged between 0.08 (Wehausen 1973) and 0.07 (Elliott, unpubl. data) deer/ha in contrast to the estimate of 0.20 deer/ha from this study. The lower limit of the 90% confidence interval approximated these earlier estimates, as did an estimate derived by simply using the total number of fallow deer sighted in prairie in 1980. We suggest that these differences resulted more from different methods of sampling and data analysis than from real shifts in population density. Densities of three fallow deer populations in England ranged from 0.38 to 6.00 animals/ha (Bailey and Putman 1981).

**TABLE 5. Fourier Series Estimate of Fallow Deer Density (N/ha) and Numbers in the Coastal Prairie Habitat Type, Southern Zone, Point Reyes National Seashore, in 1980.**

| *Deer groups/ha* | | *Deer/ha* | | *Population* | *90% Confidence* |
|---|---|---|---|---|---|
| *Density* | *S. E.* | *Density* | *S. E.* | *estimate* | *interval* |
| 0.0549 | 0.0189 | 0.203 | 0.075 | 543 | 205–881 |

The three annual estimates of black-tailed deer density in the prairie section of the southern zone showed remarkable consistency among years (Table 6). Although the estimate of deer group density was greatest in 1981, the estimate of population density was not as high, because mean group size was relatively small that year (Table 1). Considerable reduction of the standard error of the density estimate was achieved by averaging or pooling the three separate estimates. The ability to average or pool samples gathered over time permits increased precision in density estimates as monitoring continues. More precise estimates may detect long-term shifts in population densities obscured by high variance in individual samples.

**TABLE 6. Annual, Weighted Averaged and Pooled Fourier Series Estimates of Black-tailed Deer Density (N/ha) and Numbers in the Coastal Prairie Habitat Type, Southern Zone, Point Reyes National Seashore, in 1980, 1981 and 1982.**

| | *Deer groups/ha* | | *Deer/ha* | | | *90%* |
|---|---|---|---|---|---|---|
| *Year* | *Density* | *S. E.* | *Density* | *S. E.* | *Population estimate* | *Confidence interval* |
| 1980 | 0.0626 | 0.01125 | 0.127 | 0.0260 | 340 | 249–431 |
| 1981 | 0.0798 | 0.01598 | 0.138 | 0.0380 | 370 | 237–503 |
| 1982 | 0.0691 | 0.01545 | 0.142 | 0.0346 | 380 | 259–501 |
| Weighted Averaged | 0.0753 | 0.00501 | 0.145 | 0.0126 | 388 | 344–432 |
| Pooled | 0.0744 | 0.00504 | 0.144 | 0.0126 | 385 | 341–429 |

Selection of the exponential polynomial estimator in the coastal scrub type (Table 7) suggests movement of black-tailed deer away from the observers prior to detection. It may reflect greater difficulty in detecting black-tailed deer in the denser vegetation.

**TABLE 7. Exponential Polynomial Estimate of Density (N/ha) and Population Size of Black-tailed Deer in Coastal Scrub, Southern Zone, Point Reyes National Seashore, 1981.**

| *Deer groups/ha* | | *Deer/ha* | | | |
|---|---|---|---|---|---|
| *Density* | *S. E.* | *Density* | *S. E.* | *Population estimate* | *90% Confidence interval* |
| 0.0612 | 0.0207 | 0.094 | 0.033 | 324 | 127–521 |

Sample area counts (Taber and Dasmann 1955) of black-tailed deer on select sites within the Seashore's southern zone yielded density estimates of 0.06–0.17 deer/ha (Elliott 1982).

The length of transect line required to obtain future estimates of fallow and black-tailed deer densities with a confidence interval of 20% in coastal prairie are identical (Table 8). A comparable estimate for fallow deer in coastal scrub habitat type requires approximately twice the sampling effort while a comparable estimate for black-tailed deer in coastal scrub requires approximately four times the sampling intensity. This is not to imply that a specific number of transects need be established. Fewer transects may be permanently marked and sampled an appropriate number of times.

**TABLE 8. Calculated Length (km) of Transect Line Required to Obtain Estimates of Population Density with a Coefficient of Variation of 20 percent or Less for Fallow and Black-tailed Deer by Habitat Types.**

| | *Deer species* | |
|---|---|---|
| *Habitat type* | *Fallow* | *Black-tailed* |
| Coastal prairie | 43 | 43 |
| Coastal scrub | 83 | 150 |
| Mosaic | – | 42 |

**TABLE 9. Fourier Series Estimate of Density (N/ha) and Population Size of Black-tailed Deer in the Pastoral Zone, Point Reyes National Seashore, 1980.**

| *Deer groups/ha* | | *Deer/ha* | | | |
|---|---|---|---|---|---|
| *Density* | *S.E.* | *Density* | *S.E.* | *Population estimate* | *90% Confidence interval* |
| 0.0583 | 0.0143 | 0.2069 | 0.0555 | 1790 | 826–2753 |

The exponential power series provided the best fit to the data, suggesting some movement of deer away from the transect line prior to detection by the census team. The estimate of black-tailed deer density (Table 9) in the pastoral zone is higher than those derived for the southern zone. Similarly, this density estimate is higher than estimates of black-tailed deer density in a select portion of the pastoral zone obtained by drive counts (Elliott, Wehausen and Barrett, unpubl. data) or sample area counts (Elliott 1982:131). Thompson (unpubl. data) found that the widely scattered distribution of black-tailed deer made sample area counts difficult.

## CONCLUSIONS

The results demonstrate the value of line transect censuses and analysis by program TRANSECT in estimating population density and monitoring long term shifts in density.

Estimates of density and age and sex structure of fallow and black-tailed deer generated from line transect sampling on portions of the Point Reyes Peninsula suggest higher densities of both species than previously recorded. We attribute these higher estimates to differences in sampling procedures and data analysis rather than true shifts in population density. In particular, modeling of perpendicular detection functions by program TRANSECT provides a more realistic assessment of the abundance of target species. Such an assessment is a step in countering the almost universal tendency to underestimate population densities.

We recognize both sets of line transects rely heavily on the location of existing roads and trails in their design. Such counts may be biased, as roads may be constructed through habitats selected or avoided by the species in question (Norton-Griffiths 1978).Proposed modifications of census procedures presented under recommendations provide an opportunity to reduce the difficulties encountered in this preliminary study.

## RECOMMENDATIONS

The recommended procedure for estimating numbers of fallow and black-tailed deer on the Point Reyes Peninsula is as follows:

(i) Census both species throughout their total known range on the Point Reyes Peninsula to reduce the possibility of shifts in distribution affecting census results.

(ii) Distribute permanently marked transect lines randomly and independently within prairie and scrub habitat types over the total area. Transects should be located independently of roads and major trails to the extent feasible. Sampling intensity should be at the level calculated from our pilot surveys.

(iii) Establish an index of abundance for each species in all habitat types and determine the linearity of the relationship. Comparison of the index between habitat types with density estimates to those with no density estimates may provide an approximation of density in the latter.

(iv) Evaluate the potential of obtaining population estimates from change-in-ratio estimators (Hanson 1963, Paulik and Robson 1969). Values of interest include the ratio of fallow to black-tailed deer and the ratio of age classes, sexes or color phases of fallow deer prior to and subsequent to the annual reduction program. Records must be kept on the age, sex, and color phase of shot deer. Estimates could be derived from observations made while walking the line transects discussed above. Bias may occur if a certain age or sex class of the population becomes more wary than others or if fallow deer become more secretive than black-tailed deer.

(v) Count fallow deer from a helicopter or fixed-wing aircraft. Results of aerial counts could be compared to concurrent line transect ground counts. Aerial counts should be done along permanent transects from an aircraft fitted with sophisticated navigation equipment and radar altimeter to ensure the data acquired benefit from analysis by program TRANSECT. We do not suggest a double sampling design using line transects. The greatest advantage of an aerial census is the complete independence of location of transects from roads and trails, or topographic and vegetative features likely to influence locating ground transects. It is unlikely that black-tailed deer will be consistently detectable from an aircraft.

## ACKNOWLEDGMENTS

This report represents the combined efforts of a great number of people. K. Rogers and P. Sugnet surveyed trails, delineated habitat boundaries and selected transect locations in the south. A. Soost and J. Hartley re-marked transects in 1981. Seashore staff and volunteers covered many kilometers of trails conducting the censuses. M. Raphael assisted with analyses involving program TRANSECT. J. Verner and B. Noon offered constructive review of the manuscript. The senior author was supported by a fellowship from the Rob and Bessie Welder Wildlife Foundation during portions of this study. Additional support was provided by Project 3501-MS of the California Agricultural Experiment Station.

## LITERATURE CITED

Avery, T. E. 1975. Natural resource measurements. 2nd ed. McGraw-Hill Book Co., New York, NY. 339 p.

Bailey, R. E., and R. J. Putman. 1981. Estimation of fallow deer populations from faecal accumulation. J. Appl. Ecol., 18(4) : 697–702.

Burnham, K. P., D. R. Anderson, and J. L. Laake. 1980. Estimation of density from line transect sampling of biological populations. Wildl. Monogr., 72 : 1–202.

________. 1981. Line transect estimation of bird population density using a Fourier series. Studies in Avian Biology, 6 : 466–482.

Caughley, G. 1974. Bias in aerial survey. J. Wildl. Manage., 38(4) : 921–933.

Chapman, N. G., and D. I. Chapman. 1982. The fallow deer. Forest Record 124. Her Majesty's Stationary Office. 19 p.

Clark, K. E. 1982. The mammals of the Point Reyes Peninsula. Unpubl. Thesis, Univ. of California, Santa Cruz. 149 p.

Dasmann, R. F., and R. D. Taber. 1955. A comparison of four deer census methods. Calif. Fish Game, 41(3) : 225–228.

________. 1956. Determining structure in Columbian black-tailed deer populations. J. Wildl. Manage., 20(1) : 78–83.

Elliott III, H. W. 1982. A study to assess competition and carrying capacity among the ungulates of Point Reyes National Seashore. Dissertation, Univ. of California, Davis. 197 p.

________, and J. D. Wehausen. 1974. Vegetational succession on coastal rangeland of Point Reyes Peninsula. Madrono, 22(5) : 231–238.

Graham, A., and R. Bell. 1969. Factors influencing the countability of animals. E. Afr. Agric. For. J., 34 (special issue) : 38–43.

Grams, H. J., K. R. McPherson, V. V. King, S. A. MacLeod, and M. G. Barbour. 1977. Northern coastal scrub on Point Reyes Peninsula, California. Madrono, 24(1) : 18–24.

Hanson, W. R. 1963. Calculation of productivity, survival, and abundance of selected vertebrates from sex and age ratios. Wildl. Monogr., 9 : 1–60.

Heady, H. F., T. C. Foin, M. K. Hektner, D. W. Taylor, M. G. Barbour and W. J. Barry. 1977. Coastal prairie and northern coastal scrub. Pages 733–757 *in* M. G. Barbour and J. Major, eds. Terrestrial vegetation of California. John Wiley and Sons, New York, NY. 1002 p.

Houston, D. B. 1982. The northern Yellowstone elk. MacMillan Publishing Co., Inc., New York, NY. 474 p.

Jessup, D. A., B. A. Abbas, D. Behymer, and P. Gogan. 1981. Paratuberculosis in tule elk in California. J. Am. Vet. Med. Assoc., 179(11):1252–1254.

Kuchler, A. W. 1977. The map of the natural vegetation of California. Pages 909–938 *in* M. G. Barbour and J. Major, eds. Terrestrial vegetation of California. John Wiley and Sons, New York, NY. 1002 p.

Lauer, D. T. 1972. Vegetation mapping at Point Reyes National Seashore. Pages 86–95 *in* R. N. Colwell and G. A. Thorley, eds., ERTS-1 data as an aid to resource management in northern California. Center for Remote Sensing Research, Univ. of California, Berkeley. 120 p.

Longhurst, W. M., A. S. Leopold, and R. F. Dasmann. 1952. A survey of California deer herds, their ranges and management problems. Calif. Dep. Fish and Game, Game Bull. (6):1–136.

________, F. O. Garton, H. F. Heady, and G. E. Connolly. 1976. The California deer decline and possibilities for restoration. Proc. West. Sec. The Wildl. Soc., 1976 : 74–103.

Mason, J. 1970. Point Reyes, The solemn land. North Shore Books. Inverness, CA. 198 p.

National Park Service. 1976. Natural resources management plan and environmental assessment: Point Reyes National Seashore, California. Files of Point Reyes National Seashore. 159 p.

Norton-Griffiths, M. 1978. Counting animals. 2nd ed. African Wildlife Leadership Foundation, Nairobi, Kenya. 139 p.

Paulik, G. J., and D. S. Robson. 1969. Statistical calculations for change-in-ratio estimators of population parameters. J. Wildl. Manage., 33(1):1–27.

Pennycuick, C. J., and D. Western. 1972. An investigation of some sources of bias in aerial transect sampling of large mammal populations. E. Afr. Wildl. J., 10(3):175–191.

Rafiquzzaman, M. 1977. Johne's disease (paratuberculosis) in cattle and exotic deer at Point Reyes, California. Thesis, Univ. of California, Davis. 34 p.

Riemann, H. P., R. Ruppanner, P. Willeberg, C. E. Frnti, W. H. Elliott, R. A. Fisher, O. A. Brunetti, J. H. Aho, J. A. Howarth, and D. E. Behymer. 1979. Serological profile of exotic deer at Point Reyes National Seashore. J. Am. Vet. Med. Assoc., 175(9):911–913.

Schall, A. 1982. Influence de l'environment sur les composantes due groupe social chez le daim *Cervus (Dama) dama* L. Revue Ecol., (Terre Vie) 36(2):161–174.

Sokal, R. R., and F. J. Rohlf. 1969. Biometry. W. H. Freeman and Co., San Francisco, CA. 776 p.

Toogood, A. C. 1980. Historic resource study. A civil history of Golden Gate National Recreation Area and Point Reyes National Seashore, California. 2 vol. National Park Service, U.S. Dept. of the Interior. 376 p.

Taber, R. D., and R. F. Dasmann. 1958. The black-tailed deer of the Chapparal: its life history and management in the North Coast Range of California. Calif. Dept. Fish and Game, Game Bull. (8):1–163.

Van Atta, C. E. 1946. Notes on the former presence of grizzly and black bears in Marin County, California. Calif. Fish Game, 32(8):27–29.

Wehausen, J. D. 1973. Some aspects of the natural history and ecology of fallow deer on Point Reyes Peninsula. Thesis, Univ. of California, Davis. 68 p.

________, and H. W. Elliott III. 1982. Range relationships and demography of fallow and axis deer on Point Reyes National Seashore. Calif. Fish Game, 68(3):132–145.

Zar, J. H. 1974. Biostatistical Analysis. Prentice-Hall, Inc., Englewood Cliffs, NJ. 620 p.

*Calif. Fish and Game* 72(1): 62–64 1986

# NOTES

## UTILIZATION BY SALT MARSH HARVEST MICE *REITHRODONTOMYS RAVIVENTRIS HALICOETES* OF A NON-PICKLEWEED MARSH

Management plans for private duck clubs in Suisun Marsh and a recovery plan for the endangered salt marsh harvest mouse are being developed based upon assumptions that those mice require pickleweed, *Salicornia pacifica,* dominated habitats. The presence of pickleweed as the dominant plant species in the marsh has been described for salt marsh harvest mice (Fisler 1965, Shellhammer 1977, Shellhammer et al. 1982) and has been considered the necessary component of optimal habitat (Wondolleck, Zolan and Stevens 1976). Australian saltbush, *Atriplex semibaccata,* fat hen, *A. patula,* gum plant, *Grindelia cunifolia,* and cordgrass, *Spartina foliosa,* also regularly occur in lesser amounts in typical optimal marsh habitat. The importance of a dense mat of cover and network of open areas for salt marsh harvest mice has also been reported (Dixon 1909, Hooper 1944, Wondolleck et al. 1976, Shellhammer 1977).

In May 1981, during rodent trapping surveys on the California Department of Fish and Game Hill Slough Wildlife Area (eight kilometers southeast of Fairfield, Solano County, California), eleven harvest mice were captured and released during 300 trap nights of effort. The mice were identified as salt marsh harvest mice using a combination of external measurements, color patterns and behavior, assigned on a point system (Shellhammer 1984). The area appeared to contain no pickleweed and consisted of ten hectares isolated on three sides by large slough channels with a paved road on the fourth side. The area has been diked off from brackish water inundation during high tides for approximately 50 years, although it retains some standing water for approximately four months during the winter in years of high precipitation.

As a result of the discovery of salt marsh harvest mice on the area, a vegetation transect of the ten hectare site was conducted. A representative cross-section of the site was taken using the toe-point method. The vegetative transect revealed the following: fat hen 45 percent, salt grass, *Distichlis spicata*, 14 percent, annual grasses, 13 percent, baltic rush, *Juncus balticus,* 10 percent and alkali heath, *Frankinia grandiflora*, 9 percent. Several other plant species occurred on the site, including pickleweed, but each constituted less than one percent of the total vegetative cover. Fat hen was quite dense and provided excellent cover for the mice. This is the second report where salt marsh harvest mice were found to inhabit an area not dominted by pickleweed and the first for the northern subspecies. Rice (1974), found areas containing fat hen were actually preferred, while areas containing pickleweed were avoided by the southern subspecies of the salt marsh harvest mouse, *R. r. raviventris*. Zetterquist (1977) in her work in the south San Francisco Bay concluded that her findings invalidated the idea that *R. r. raviventris* occurs only in tidal salt marshes and that marginal areas should be preserved in present condition or expanded.

This report is in accord with Rice's 1974 work and expands upon Shellhammer's 1982 findings. Further sampling and study are necessary to determine the extent and intensity of use in such areas by salt marsh harvest mice. Additional findings may shed more light on the biology of the salt marsh harvest mouse and have a bearing on management programs being developed to ensure the continued survival of this animal. Additional "marginal" areas should be examined. No changes in current management practices affecting the salt marsh harvest mouse are justified at this time. However, these findings indicate marginal areas may be important to salt marsh harvest mice and such areas should not be written off to development without investigation.

## LITERATURE CITED

Dixon J. 1909. A new harvest mouse from Petaluma, California. Univ. Calif. Publ. Zool., 5 : 271–273.

Fisler, G.T. 1965. Adaptations and speciation in harvest mice of the marshes of San Francisco Bay. Univ. Calif. Publ. Zool., 77: 1–108.

Hooper, E.T. 1944. San Francisco Bay as a factor influencing speciation in rodents. Misc. Publ., Mus. Zool., Univ. Mich. 59: 1–89.

Rice, V.C. 1974. The population ecology of the salt marsh harvest mouse at Triangle Marsh. Thesis. San Jose State Univ.

Shellhammer, H. 1977. Of mice and marshes. San Jose Studies., 3(1): 23–25.

_______1984. Identification of salt marsh harvest mice, Reithrodontomys raviventris, in the field and with cranial characteristics. Calif. Fish Game, 70(2): 113–120.

_______, R. Jackson, W. Davilla, A. Gilroy, H.T. Harvey and L. Simons. 1982. Habitat preferences of salt marsh harvest mice (Reithrodontomys raviventris). Washmann J. Biol., 40(1–2): 102–114.

Wondolleck, J.T., W. Zolan, and G.L. Stevens. 1976. A population study of the harvest mouse (Reithrodontomys raviventris Dixon) in the Palo Alto Baylands salt marsh. Wasmann J. Biol., 34(1): 52–64.

Zetterquist, D.K. 1977. The salt marsh harvest mouse (Reithrodontomys raviventris raviventris) in marginal habitats. Wasmann J. Biol., 35(1): 68–76.

*—Fred Botti, Dee Warenycia and Dennis Becker, California Department of Fish and Game, Region III, P. O. Box 47, Yountville, California 94599.* *Accepted for publication December 1984.*

# A METHOD FOR THE EFFICIENT REMOVAL OF JUVENILE SALMONID OTOLITHS

During 1981 and 1982, juvenile steelhead rainbow trout, *Salmo gairdneri* Richardson, were collected from three northern California watersheds for a California Department of Fish and Game funded study on the racial analysis of juvenile summer and winter steelhead and resident rainbow trout (Winter 1983). The fish were frozen for later removal and analysis of otoliths and otolith nuclei as described by several authors (Kim 1963; McKern, Horton, and Koski 1974; Rybock, Horton, and Fessler 1975). Three pairs of otoliths are found in the inner ear of steelhead but only the largest pair, the sagittae, are used for age and racial studies so use of the term "otolith" refers to the sagittae.

I soon discovered that the typical method of otolith removal, splitting the head, was inadequate for thawed young-of-year steelhead since even razor blades would mash the head before the blades would cut. McKern and Horton (1970) described a punch that expedited removal of otoliths from larger steelhead. However, a punch delicate enough for use on young-of-year fish was not feasible. A method of otolith removal that did not result in mashed heads or the loss of otoliths by having to probe for the granular otoliths was developed.

The otoliths were obtained from the fish by first removing the lower jaw and all of the gill rakers to expose the neurocranium. For young-of-year fish, the otoliths were visible through the semi-transparent walls of the neurocranium and were easily removed by puncturing the walls with No. 5, fine-tipped forceps and pulling out the otoliths. For yearling and older fish, the neurocranium is opaque and prevents visual location of the otoliths. In these cases, a probe was forced through the neurocranium directly anterior to the area containing the otoliths (Figure 1). The fish were then grabbed between thumb and forefinger on either side of the incision and bent backwards, thereby rupturing the neurocranial cavity. The otoliths were then clearly visible in the posterior portion of the neurocranium and were removed with fine-tipped forceps. The sacculus, the membranous sac surrounding each sagitta, was removed by rubbing each otolith between thumb and forefinger and the otoliths placed in water filled glass vials for storage. This procedure was also used on several adult steelhead with success but heavy scissors or wire cutters are recommended for cutting away the lower jaw.

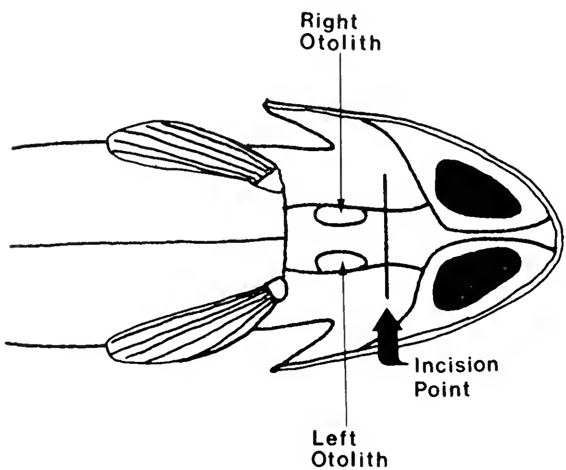


FIGURE 1. Ventral view of a young-of-year steelhead rainbow trout with lower jaw and gill rakers removed, showing location of otoliths and neurocranium incision point.

## LITERATURE CITED

Kim, W.S. 1963. On the use of otoliths of red salmon for age and racial studies. Thesis. Univ. of Washington, Seattle, WA.

McKern, J.L., and H.F. Horton. 1970. A punch to facilitate the removal of salmonid otoliths. Calif. Fish Game, 56(1):65–68.

McKern, J.L., H.F. Horton, and K.V. Koski. 1974. Development of steelhead trout (*Salmo gairdneri*) otoliths and their use for age analysis and for separating summer from winter races and wild from hatchery stocks. Can., Fish. Res. Bd., J., 31:1420–1426.

Rybock, J.T., H.F. Horton, and J.L. Fessler. 1975. Use of otoliths to separate juvenile steelhead trout from juvenile rainbow trout. Fish. Bull., 73(3):654–659.

Winter, B.D. 1983. Racial analysis of juvenile summer and winter steelhead and resident rainbow trout (*Salmo gairdneri* Richardson) from three northern California watersheds. Thesis. Humboldt State Univ., Arcata, CA.

*—Brian D. Winter, Fisheries Resource Management, Nez Perce Tribe, P.O. Box 365, Lapwai, ID 83540.* *The work reported was done as part of a Master's thesis at Humboldt State University. Accepted for publication March 1985.*

*Photoelectronic composition by*
CALIFORNIA OFFICE OF STATE PRINTING

85—80768 800007

# INSTRUCTIONS TO AUTHORS

## EDITORIAL POLICY

*California Fish and Game* is a technical, professional, and educational journal devoted to the conservation and understanding of fish and wildlife. Original manuscripts submitted for consideration should deal with the California flora and fauna or provide information of direct interest and benefit to California researchers. Authors may submit an original plus two copies, each, of manuscript, tables, and figures at any time.

**MANUSCRIPTS:** Authors should refer to the *CBE Style Manual* (Fifth Edition) and a recent issue of *California Fish and Game* for general guidance in preparing their manuscripts. Some major points are given below.

1. *Typing*—All material submitted, including headings, footnotes, and literature cited must be typewritten doublespaced, on white paper. Papers shorter than 10 typewritten pages, including tables, should follow the format for notes.

2. *Citations*—All citations should follow the name-and-year system. The "library style" will be followed in listing references.

3. *Abstracts*—Every article must be introduced by a concise abstract. Indent the abstract at each margin to identify it. Abstracts, on separate sheets of paper, should accompany "Notes".

4. *Abbreviations and numerals*—Use approved abbreviations as listed in the *CBE Style Manual*. In all other cases spell out the entire word.

**TABLES:** Each table should be typewritten with the heading left margin justified. Tables should be numbered consecutively beginning with "1" and placed together in the manuscript following the Literature Cited section. Do not double space tables. See a recent issue of *California Fish and Game* for format.

**FIGURES:** Consider proportions of figures in relation to the page size of *California Fish and Game*. The usable printed page is 117 by 191 mm. This must be considered in planning a full page figure, for the figure <u>with its caption</u> cannot exceed these limits. Photographs should be submitted on glossy paper with strong contrasts. All figures should be identified with the author's name in the upper left corner and the figure numbers in the upper right corner. Markings on figures should be made with a blue china marking pencil. Figure captions must be typed on a separate sheet headed by the title of the paper and the authors name.

**PROOFS:** Galley proofs will be sent to authors approximately 60 days before publication. The author has the ultimate responsibility for the content of the paper, and is expected to check the galley proof very carefully.

**PAGE CHARGES AND REPRINTS:** All authors will be charged $35 per page for publication and will be billed before publication of manuscripts. Reprints may be ordered through the editor at the time the proof is submitted. Authors will receive a reprint charge schedule along with the galley proof.

POSTMASTER: RETURN POSTAGE GUARANTEED

Editor, CALIFORNIA FISH AND GAME
CALIFORNIA DEPARTMENT OF FISH AND GAME
1416 NINTH ST., SACRAMENTO, CA 95814

BULK RATE
U.S. POSTAGE
**PAID**
Sacramento, Calif.
Permit No. 949